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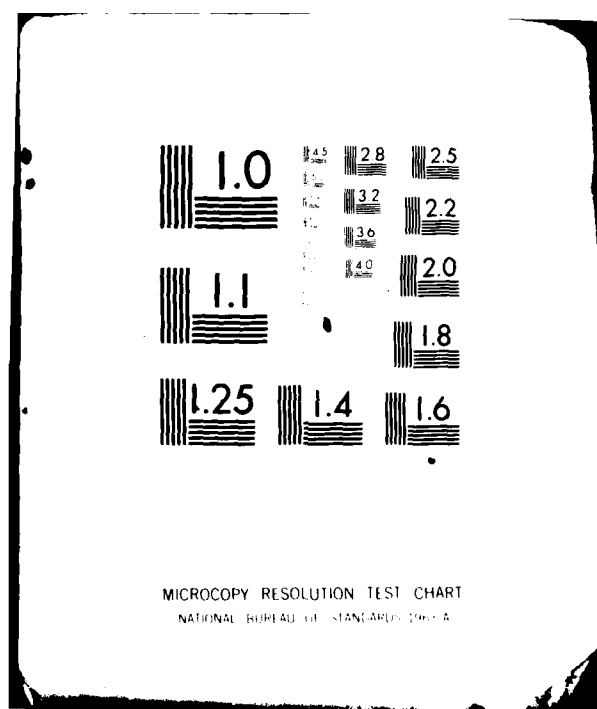
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STIP VII: FOUR NEIGHBORING RADIO PATHS
TRAVERSE THE NORTHERN CORONA IN 1979

Thomas A. Croft

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025

Final Report
May 1979 - September 1981

December 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) If spacecraft could be seen in the sky, then in August and September of 1979 a unique "parade" of spacecraft could have been observed. With reference to the ecliptic plane, Pioneer Saturn, Voyager 1 and Voyager 2 appeared to move from left to right, about one degree north of the sun, while Pioneer Venus traversed the same path from right to left. Because the influence of the sun on radio signals is concentrated in the region nearest the sun, we were able to use the radio signals from these four spacecraft as probes of the solar corona. The spacecraft parade offered two types of opportunities that are closely		

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20. Abstract (continued)

related: first, those due to the multiple observations in the same region of the corona, and second, the three opportunities when pairs among the four spacecraft passed close to one another in the sky. Because Pioneer Venus traveled eastward relative to the sun while the others traveled westward, it follows that Pioneer Venus made a close approach to each of the other three. The value of data emerging from these interplanetary recording sessions is enhanced because the events occur in the midst of STIP Interval VII during which the northern and equatorial corona were monitored by many diverse techniques. The gathering of four spacecraft behind the northern corona serves as a means for tracking the macroscopic flow patterns in the corona and relating the patterns to scintillations (measured from the spacecraft) white-light coronagraphs (sensitive to the same electrons but throughout the region), high-energy particle distributions, radio noise bursts, spectroheliograms, magnetograms, radio-star scintillations, and the like.

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CONTENTS

I	INTRODUCTION	1
II	THE TIMES OF HELIOCENTRIC RADIAL ALIGNMENTS	5
	A. The First Close Encounter	5
	B. The Second Close Encounter	7
	C. The Third Close Encounter	7
III	WIDE-AREA SAMPLING IN THE NORTHERN CORONA	9
	A. Data Availability by the Hour	11
	B. Physical Basis of Measurements by the Four Spacecraft	13
IV	THE DOPPLER NOISE MEASUREMENT	15
V	MEASUREMENTS OBTAINED BY THE FOUR PRIMARY SPACECRAFT	17
	A. Results of the First Close Encounter	18
	B. Results of the Second Close Encounter	19
	C. Results of the Third Close Encounter	22
	D. Graphical Representation of Signal Characteristics	23
VI	RESULTS FROM MULTIPLE SPACECRAFT CORRELATIONS	29
VII	SOURCE OF THE "DOPPLER NOISE"	31
VIII	DOPPLER NOISE RESULTS FOR ALL SPACECRAFT	33
IX	OTHER DATA OF VALUE IN CORRELATIVE STUDIES	38
X	CONCLUSIONS	45
	ACKNOWLEDGMENTS	47
	REFERENCES ,	48
	LIST OF TABLES	50
	TABLES	51
	FIGURE CAPTIONS	61
	FIGURES	63

I INTRODUCTION

If people could see spacecraft in the sky as stars are seen at night, they would have seen a remarkable coincidence in August and September 1979. On viewing the sun and using as a horizon reference the ecliptic plane, viewers would have seen Pioneer Venus move slowly from right to left in passing nearly behind the sun, but staying just above (north of) it. At about the same time Voyager 2 would move from left to right through the same region behind the sun followed shortly by Voyager 1 and by Pioneer 11. The latter spacecraft passed by Saturn just before going behind the sun. Remarkably, each of the four spacecraft passed about 1° north of the sun, as measured at the eye of the observer.

Because Pioneer Venus was headed east (relative to the sun and in the astronomical sense) while the other three spacecraft were headed west, it follows that there was a point of closest approach between the radio path from Earth to Pioneer Venus and that to each of the other spacecraft. More importantly, there was a nearby point at which each close pair of radio paths and the center of the sun lay in the same plane. At that moment, the plasma which passed through the nearer radio path then moved radially outward and passed through the farther path at a slightly later time. This allowed radio scientists an unprecedented opportunity to observe the same plasma at two different points during its transit outward from the sun. Three such opportunities existed in a matter of about three weeks.

In addition to these opportunities for observing the same plasma at two points in its path, a broader opportunity for observing the trends

in solar eruptive activity in its northern coronal region was available to radio experimenters by virtue of the continued existence of multiple radio paths in the region during August and September. The measurements of radio signal scintillation were expected to be accompanied by measurements of total electron content made possible by the dual frequency ranging on both Voyager spacecraft. The content yields an indication of the average density of the corona, whereas the scintillation provides a measure of the turbulence-induced density differences from place to place. Thus the two types of measurements complement each other as a means for gaining information about the status of the corona plasma.

The author has the unique good fortune to be a member of both the Pioneer Venus Radio Science Team and the Voyager Radio Science Team. Membership in these teams entails years of work as an advisor during the design of the spacecraft and of the mission. The reward for this work is a greater opportunity to initiate scientific observations with the spacecraft and an initial access to the resulting data. The performance of scientific observations with both Pioneer and Voyager spacecraft, as is made desirable by the opportunities of August and September, required action by the two radio science teams. In fact, it was because I was a member of both teams that I started performing correlative trajectory studies in 1976 and discovered that the four spacecraft would go behind the sun at the same time.

The measurements of scintillation caused by variations in electron concentration can often serve in isolation as a source of worthwhile scientific information. Nevertheless, experience has shown that the

value of the data is increased markedly through collaboration with other solar and solar corona observers and correlation among diverse data types. This is in fact the type of activity encouraged by the Study of Traveling Interplanetary Phenomena, STIP. As a result, when it became clear that the National Aeronautics and Space Administration (NASA) would allow measurements during the multiple conjunction, I suggested to Dr. Murray Dryer (SCOSTEP's STIP convener) and to his collaborator (Dr. M. A. Shea, secretary) that August and September 1979 should be declared a STIP Interval. Dr. Dryer and Dr. Shea concurred and declared the event to be STIP Interval VII [Svestka and de Jager, 1980]^{*}.

While the four spacecraft may have appeared to be close together in the sky as seen from Earth, they were widely scattered when all three dimensions were considered. Pioneer 11, also known as Pioneer Saturn, was so far away from Earth that a round trip at the speed of light required 2.9 hours. Voyagers 1 and 2 were both at a somewhat lesser distance with a round-trip light time of some 1.9 hours. In contrast Pioneer Venus was in orbit around its namesake planet and the round trip required only 30 min.

From the standpoint of the radio science experiment, these differing distances were largely immaterial because the most extreme influence of the plasma medium on the radio signal occurred in the region where the signal made its closest approach to the sun. Figure 1 is a sketch designed to emphasize this important concept. The solar wind and corona

^{*}References are listed at the end of this report.

density varies in approximate proportion to the inverse square of the distance from the sun, under idealized, steady-state conditions. There appears to be a tendency for the gradient to be even stronger in the regions nearer to the sun. Radio signal disturbances are, in the last analysis, attributable to variations of the refractive index and these, in turn, are approximately proportional to the concentration of the plasma. Thus, the signal variations are related to electron-number density gradients caused by turbulence or waves. Such variations are much stronger at the point nearest the sun where a comparatively dense body of plasma resides. This is the region of greatest sensitivity of the radio signal to plasma variations as depicted in Figure 1. It matters little how far the spacecraft may be from Earth so long as they are beyond the sun. Comparatively little happens to the signal as it travels into the outer solar system where Jupiter and Saturn orbit. Radio measurements during a superior conjunction, therefore, reveal little about the environment near the planets, but they provide excellent indications of the physical conditions in the corona.

Three fortunate aspects of the happenstance in August and September were that (1) the four spacecraft were all close together, (2) all in the same side of the ecliptic plane, and (3) moving in opposite directions through a somewhat narrow channel.

II THE TIMES OF HELIOCENTRIC RADIAL ALIGNMENTS

Heliocentric radial alignments of the signal paths from pairs of spacecraft offered unusual opportunities for radio scientific investigations that had never been exploited before. One such alignment would be notable, so the occurrence of three of them in a 19-day period was exceptional. In view of the decreasing pace of space exploration in this coming decade, such a triple event will probably not recur for many years. At the time when these concepts were being communicated to the scientific community, a curiously named science fiction film was reaching its peak of popularity and as a consequence, the heliocentric radial alignments became known as "close encounters." While the name is somewhat misleading, it has been readily adopted without any apparent harm, and I will continue to use it. This name was first used in publication when the Transactions of the American Geophysical Union devoted a page to the notification of collaborators. [EOS, October 1978].

A. The First Close Encounter

Because Voyager 2 led the group of three spacecraft moving to the west, its path was the first to be radially aligned with that to Pioneer Venus. Many of the important details concerning this first of the close encounters are depicted in Figure 2. On that figure, Part (a) is drawn to scale in the plane containing the sun that is perpendicular to the Earth-sun line. The track of Voyager 2 moving to the west (to the right in this figure) is shown with a dot each day at 00 UT. Above that and moving east is the track of Pioneer Venus, similarly marked. The horizontal line through the Sun is the ecliptic plane, with a vertical line directed north. The tick marks on the ecliptic plane and

on the northward line segment refer to elongation, the angles subtended at the Earth with reference to the Earth-sun line.

Shortly after 00 UT on August 17, the radio paths to the two spacecraft attained the same heliocentric ecliptic latitude of 23.4°N . The solar wind is known to flow nearly along radial lines extending from the sun, so it follows that the plasma along the Voyager 2 path should shortly thereafter fill the Pioneer Venus path. At this close encounter, the angle between the two spacecraft (as seen at Earth) was only 0.9° .

Further insight concerning this encounter is provided by the perspective sketch in Figure 2(b), not drawn to scale. The distances from the sun and between the two paths are given in units of the solar radius. Within $\frac{1}{2}$ AU of the sun, the path from Voyager 2 lies in plasma that will shortly fill the entire length of the radio path from Pioneer Venus. However, the distance that the solar wind plasma must travel from one path to the other depends on the location along the path; as one moves away from the point along the path nearest the sun, the plasma moving on a more oblique path must travel farther than 3.2 solar radii to make the trip from one radio signal path to the other. Thus the value of 3.2 solar radii is a minimum found only at the perihelion of the path. This situation is further complicated by the fact that the solar wind speed varies in different directions; therefore, we expect that the time of travel from one spacecraft path to the other will take on many values at different points along the path. Still, events near path perihelion (characterized by the 3.2 solar radius value) will dominate because the corona is most dense there. Evidences of delay

from one signal to the other that may be measured are likely to reflect events in the plasma that occur near this point of closest approach to the sun.

B. The Second Close Encounter

In many ways, the encounter shortly after midday on August 23, depicted in Figure 3, was the best of all. These paths were extremely close to one another, as may be seen by reference to Parts (a) and (b) of the figure. It was expected that the corona plasma might make the transit between these two paths in as little as ten minutes. Additionally, this event occurred at the highest latitude among the three encounters, and so it offered a special opportunity for observing the high-latitude corona concerning which there are as yet many unanswered questions. At the time when this event was first visualized, the so-called "international solar-polar mission" (ISPM) was in a formative stage and we hoped to contribute knowledge of the corona that might prove helpful in that effort. These observations now take on added significance for out-of-ecliptic science now that half of the ISPM has been cancelled at this writing.

C. The Third Close Encounter

Only four days after going by Saturn, Pioneer 11 made its close encounter with Pioneer Venus late on September 5. In many ways this was the least desirable of the encounters. Pioneer 11 was a comparatively primitive craft intended for initial exploration, and it lacked the dual-frequency capability of Pioneer Venus and the dual frequency ranging capability of the Voyagers. Both of these missing elements

hinder our ability to sense environmental conditions by means of the precise measurement of relative effects on the two radio signals. Furthermore, this encounter was at the largest distance from the sun and at the lowest latitude. In compensation for these disadvantages, Pioneer 11 had an advantage: it was in its "prime mission" phase for the Saturn Encounter and, therefore, was being given top priority by the Deep Space Network (DSN) of receiving stations. The result was that many long records from Pioneer 11 could be readily obtained, whereas each short record from the other three spacecraft had to be prearranged at the expense of an extensive liaison effort. As we shall see, this advantage of Pioneer 11 was the dominant influence and, as a result, this third encounter was the most successful. It is depicted in Figure 4, which is much like the two preceding figures except that Part (a) combines information from all three encounters in one graph. This latter graph is a key drawing and will be found to summarize in compact form much quantitative information concerning all four spacecraft.

III WIDE-AREA SAMPLING IN THE NORTHERN CORONA

Although the close encounters attracted attention by their novelty, they actually formed only a part of the overall opportunity for collaboration in observing traveling interplanetary phenomena. It is perhaps more significant that there were numerous spacecraft simultaneously in position to yield information about the solar corona and solar wind, and particularly about the northern reaches of this region, during STIP Interval VII.

The overall situation is summarized in Figure 5 which extends 36° to the east and west of the sun. A word of caution; the drawing is anamorphically compressed so that the north-south axis is twice the scale of the east-west axis. In Figure 5(a), we see the track of Voyager 2 from July 10 through the end of the interval. In Figure 5(b), Voyager 1 is shown during the same period, being about 0.4° farther north and running eight days behind Voyager 2. Figure 5(c) shows the apparent motion of Pioneer 11 which seems to move westward faster than the Voyagers. Actually the angular speed of the Voyagers and of Pioneer 11 around the sun is eastward in an inertial frame but much slower than that of the Earth. This appearance of motion toward the west illustrates that the outer planet explorers are relatively stationary in the sky (at least in angular position as seen at Earth). The apparent motion to the west relative to the sun is caused more by the movement of the Earth than by the movement of the Voyagers or Pioneers. In Figure 5(c), Pioneer 11 appears to move faster because it is farther out in the solar system and so even more stationary in the sky than are the Voyagers. A fixed star would appear to move to the right at a rate of 360° per year.

In contrast to the outer planet explorers, Pioneer Venus moves to the left in the plot of Figure 5(d). It is in orbit around Venus that has a higher angular rate around the sun than does Earth, so near superior conjunction it appears to move to the east. In this manner some spacecraft appear to go west and others appear to go east, even though all of them journey around the sun with the Earth in the same direction.

In contrast to the foregoing, Helios 1 and 2 are in highly eccentric orbits. When these are drawn relative to a stationary Earth-sun line, the apparent Helios motion varies greatly during the passage of a few months. Both Helios spacecraft remain nearly in the ecliptic plane, and their positions from July 10 through September 10 are depicted in Figure 5(e). After September 10, both spacecraft were virtually stationary on this diagram until the end of STIP Interval VII. The Helios orbits had aphelia near the orbit of Earth and perihelia at ≈ 0.3 AU inside the orbit of Mercury. Frequent superior conjunctions occurred as a result. It may be seen in Figure 6 that STIP Interval VII was just a month or two too early from the standpoint of Helios. If the interval had spanned October and November, both of these spacecraft would have passed behind the sun and the correlations with Pioneer Venus, Voyager and Pioneer Saturn would have been more productive from the standpoint of the radio science discussed here. Because the spacecraft were so far from the sun during August and September, no attempt was made to study the radio signal carrier. Instead only the instrumentation aboard the Helios craft was to be used as a basis for acquiring correlative information.

To show how the spacecraft fit together, one might make a motion picture or a series of images showing successive positions of all the spacecraft. This has not yet been done, but in Figure 5(f) we do show one such set of positions on August 20, 1979, midway between the first and second encounters. It is clear that the sampling of the solar wind and corona could be fairly thorough if all spacecraft produced data amenable to correlative study.

A. Data Availability by the Hour

To facilitate data correlation with other observers, we have maintained a tabulation by digital computer showing the times during which measurements were obtained and have been conveyed by tape recording to us from the four participating spacecraft. These are summarized in Tables 1 through 8. Much of the symbolism is explained in the footnote on Table 1, but the meanings of the symbols D and L, require some explanation. D signifies closed-loop data, and L symbolizes linear recordings on open-loop data. The "loops" referred to in these names are phase-locked loops in radio receivers. A closed-loop record refers to recordings made through the action of an actual radio receiver which maintained a phase-locked loop in lock and thus yielded such parameters as the frequency and strength of the signal. One of the main parameters we recover from the closed-loop data is the Doppler noise, concerning which much more will be provided later. The linear recordings contain a band of noise which is thought to contain the signal. This band is converted to a time-varying voltage that is subsequently digitized, and the record provided to the experimenter is then a string of digits. From this, the scientist reconstructs a waveform and performs a simulated phase-locked loop

receiver function using a computer program instead of an electronic device. The signal is detected by this means and its radio frequency or phase are then recorded for subsequent manipulation. The method is inherently tedious and expensive, but very powerful because processes can be performed that are otherwise impossible, both because of radio hardware limitations and because of the limitations of physical reality. As an example, time can be run backwards and this often has a decided advantage to the experimenter. Similarly, there are types of filters that can be implemented in a computer program that cannot be built in a real electronic receiver.

From the linear recordings we obtain subtle measurements of signal scintillation, and in some cases a more accurate derivation of frequency or signal strength. When multipath propagation occurs, the linear recordings are the only means whereby the multiple signals can all be discerned. For passages quite near the sun, this may be a crucial advantage.

The tables provide a value of D and of L whenever the data exists during the hour in question. No round-off or truncation is entailed; rather, a D or an L is plotted if any data of that type occurs during the particular hour no matter how short the record may be. Collaborators who wish to obtain information about some period with a finer time resolution than is provided by these tables will find it necessary to contact the author to obtain this information. It is hoped that the needs of most would-be collaborators are met by the information in the table, which covers all four spacecraft during STIP Interval VII.

B. Physical Basis of Measurements by the Four Spacecraft

When a radio signal travels through interplanetary space, its progress is slowed somewhat because of the presence of free electrons. At the same time, the wavefront speed increases to slightly faster than the speed of light. These effects are used to determine plasma density through measurement of the signals to or from spacecraft. The measurement system determines the total amount that the radio transit time is affected by the action of the free electrons along the path. To pass from the Earth to a spacecraft, the radio signal must be able to penetrate the Earth's ionosphere; therefore, the radio frequency must be many tens of megahertz. The lowest frequency ever used for this purpose was 49.8 MHz; then, transionospheric propagation nonlinearities contributed significantly to the total system error [Croft, 1973]. To avoid this difficulty the Pioneer Venus and Voyager spacecraft use 2300 MHz as the sensor signal.

Even when the spacecraft is far from Earth in the solar system, the total accumulated delay caused by electrons in the solar wind is very small. The measurement of microseconds after the lapse of a few months implies a time stability of one part in 10^{13} over that period. At the present time, such performance by a space-qualified clock is beyond the state of the art. Therefore, it follows that the direct measurement of the travel-time effect is not possible for a single-frequency spacecraft such as Pioneer 11.

Nevertheless, measurements of the electron-induced delay have been obtained already by spacecraft that made just this measurement. To achieve the required precision in time delay observations, it was

necessary to take advantage of the dependence of the plasma-induced delay upon radio frequency; the amount of the delay varies as the inverse square of the radio frequency. Therefore, one can transmit at two frequencies, with appropriate synchronization, and measure the relative group time delays of these signals [Kelso, 1959]. The difference between the delay at a low frequency, F_L and a high frequency, F_H , varies as

$$\frac{1}{F_L^2} - \frac{1}{F_H^2} .$$

It is convenient, but not necessary, for the second term to be negligible in comparison with the first. In the system used, the second term is 7.5 percent of the first term.

The discussion above pertains to the measurement of the modulated signal transit time; that is, the measurement of group delay along the path. The measurement of phase delay is not possible because there is no way to identify specific wave fronts, but changes in the phase delay are readily observed in the form of Doppler shifts. Eshleman et al., [1960] pointed out that the same two-frequency method could be used to good advantage in the measurement of differential Doppler shift for the purpose of observing the time rate of change of the electron content of a radio path.

IV THE DOPPLER NOISE MEASUREMENT

Dr. A. L. Berman of the Jet Propulsion Laboratory (JPL) has been working to establish the validity of a "Doppler noise" parameter as a measure of conditions in the solar wind through which the radio signal from the spacecraft propagates. It is his contention that the parameter can serve as a good indicator of conditions in the corona and solar wind even though it is derived with minimal effort during ordinary DSN tracking. In this role, it serves in place of the scintillation index that is conventionally derived from linear recordings at a cost of considerable computer time. In an early work, Berman and Wackley [1977] showed that the Doppler noise variations during a solar conjunction followed trends much like those of electron content. The noise is closely related to the scintillation index (SI) which in turn is related to irregularities in refractive index attributable to turbulence in the plasma. As a spacecraft approaches superior conjunction and its radio path approaches the sun, the associated electron content rises, the refractive index departs farther from unity, and thus turbulence becomes more effective in scintillating the signal. The end result, illustrated by the data of Renzetti and Berman in Figure 10, is that Doppler noise and electron content increase hand-in-hand as a radio path approaches the sun. However the noise and the SI are not consistently proportional to content since the corona or solar wind may be dense but calm for a time, and the scintillation will then be disproportionately low.

The advantage of this noise parameter is its low cost and ready availability as a natural adjunct to the operation of the DSN receivers. In contrast, a conventional determination of the SI requires the processing of open-loop recordings, (coded L in tables 1 to 8) which are essentially wideband tape recordings of the signal-plus-noise before any attempt to detect the signal by radio means. This requires the application of subsequent computer processing wherein the entire wide-band signal is digitized and a synthetic radio receiver is represented in software. With this kind of expense and effort, sophisticated results can be achieved, but the number of hours of data that can be processed is limited by budgetary considerations.

For the 1979 event, we needed many days of observation, but our objectives did not hinge upon the computation of scintillation spectra or the SI, so long as the chosen index indicated the state of the solar wind. The Doppler noise appears to fulfill this requirement.

V MEASUREMENTS OBTAINED BY THE FOUR PRIMARY SPACECRAFT

The dominating influence on the radio measurements during August and September was the passage by Saturn of Pioneer 11 at the mid-point of the interval. This was not only mankind's first chance to obtain close observations of Saturn, but also it provided vital information for programming the Voyagers that were soon to come. Nothing was done in the interest of the parade of spacecraft that might have jeopardized the Pioneer 11 encounter.

Although there are several paraboloidal antennas at each of the DSN stations (California, Australia and Spain), nevertheless each site possesses only one 64-m antenna; all others are significantly smaller. The full performance capability of these larger antennas was required for the Pioneer 11 passage and yet (at this time) only the 64-m stations were equipped to receive the dual-frequency signals from Pioneer Venus and the Voyagers. There was one exception to this generalization: The 34-m dish at Goldstone, California could also perform this task. As a result of this dependence on the three 64-m receivers, a dependence shared by Pioneer 11 and by the parade of spacecraft observations, the only time that could be devoted our corona observations was that brief overlap interval during which two stations on Earth could simultaneously observe the four spacecraft. Of course, this situation was made worse by the fact that all four spacecraft were essentially at the same point in the sky, so they rose and set together each day.

If all three stations were equally spaced around the equator and

if the observed spacecraft were also in the equatorial plane, then a twelve-hour track would commence once each eight hours and there would be three four-hour periods each day during which two receivers could operate simultaneously. Actually all three receivers are at latitudes exceeding 35° , with two in the northern hemisphere and one in the south, and the spacecraft were not in the equatorial plane. As things worked out, there were three overlaps every day of which two lasted about four hours; the third was too short to be useful for our purposes. Considering the severity of these restraints, we must acknowledge the skill and cooperative spirit of those at JPL who plan and control the tracking time schedule. A great deal of the available overlap schedule was indeed devoted to monitoring the Voyagers and Pioneer Venus for the purpose of this set of observations. In addition, each of the three close encounters was assigned considerable tracking time during the overlap opportunity that was closest in time to the optimum moment. Through a stroke of good luck, two of the three encounters happened to fall within overlap periods.

Concerning the schedule, then, one can say that the occurrence of the Pioneer 11 encounter with Saturn was a major impediment to the experiments within the advocacy of the present scientific context. The tracking which was scheduled for the parade of spacecraft was about as generous as one could reasonably have hoped to acquire.

A. Results of the First Close Encounter

Long after the tape recordings were acquired from the station and processed by us, with a puzzling lack of correlation, we learned that the record obtained from the Australian DSN was at precisely the right time

of day, but on the wrong day. This unfortunate turn of events destroyed the value of the encounter, although of course the tracking is valuable in the more general sense. It has not been possible to track down the source of the error. Some users of Figure 4(a) have been confused by the assignment of numbers to dots along the spacecraft trajectories signifying the point where the spacecraft was located at 00 UT. Because three spacecraft go right and one goes left, it is easy to make a mistake as to the date of a line segment between labeled dots. I point this out in the hope that it may help others to avoid the problem; clearly, it is better to label the line segments than the dots in such a diagram. We may never know the root cause of the tracking time error on August 17; it may have been related to the drawing.

B. Results of the Second Close Encounter

Again I must regretfully relate that a failure occurred eliminating this, the most valuable close encounter of the three. The personnel who had the task of controlling Pioneer Venus were also called upon to participate in the control of Pioneer 11, which was scheduled to go by Saturn a week after the second close encounter. Anticipating that Pioneer Venus would have to run virtually unattended, they decided to switch from the high-gain to the low-gain spacecraft antenna. The high-gain antenna yields a much stronger signal at Earth, but only when the spacecraft attitude is correct. Because of its relative directivity, the antenna produces a negligible signal at Earth if the aiming is incorrect. In contrast, the low-gain antenna is nearly isotropic. Thus, no matter what the spacecraft attitude, some weak signal would still reach Earth. Of course the same logic applies to the signal from Earth to the spacecraft;

the ground controllers would be unable to reach the spacecraft if it were hooked to the high-gain antenna and the spacecraft antenna was not correctly aimed.

In interplanetary exploration, it is not uncommon to "lose" a spacecraft (i.e., lose the ability to communicate with it) for a period of time, particularly after a solar conjunction when communication is interrupted for weeks. Once lost, the search to reacquire communication with the spacecraft must be conducted in two dimensions: space and frequency. The Earth antenna must be aimed at the spacecraft and the receiver must operate at the correct frequency. In the usual circumstance, adequate information is available to permit the correct aiming of the Earth antenna, but the correct frequency depends on the irregular and unpredictable trends that occur in key components of the spacecraft radio receiver. These values change with the passage of time so that the correct frequency may lie in a large bandwidth if a long time has elapsed since the spacecraft was last in contact. In addition to this hazard, the Pioneer project leaders could envision certain untoward circumstances that might arise during the superior conjunction in which the Pioneer Venus spacecraft might damage itself. It was ascertained that these circumstances could not arise when the low-gain antenna was used, and so there was a safety feature added to the arguments in favor of the low-gain decision.

Recognizing that the weak signal provided by the low-gain spacecraft antenna would impose a difficult task on the Goldstone DSN operators, I traveled to Goldstone on the day before the second close encounter to talk to the crew about procedures that might be used in an effort to make this encounter work. In particular, a spectral signal indicator, recently

installed, had been found an excellent indicator of the presence of a weak signal. We planned to make much use of it. Because of the short time for transit of plasma between the two spacecraft, possibly as little as ten minutes, we discussed means for making the changeover quickly. It is interesting that this changeover requires an hour in routine nominal planning. It was generally accepted that 30 minutes was a reasonable changeover time when some reason for speed existed. On discussing the particular features of this encounter, it was determined that the unusual proximity of the two spacecraft in the sky would make manual dish steering possible, thus saving a great deal of time. It was later reported that the change was made in 50 seconds. Unfortunately, after the switchover to Pioneer Venus, it was never possible to acquire a lock on the signal. The low-gain antenna rendered this signal too weak for detection so close to the sun.

The original linear recording tape made at Goldstone on August 23 was brought to SRI International and repeated attempts were made to detect the Pioneer Venus signal after the changeover. All failed. The Voyager personnel on the Radio Science Data Team at JPL suggested that they might try their existing software in an effort to detect the signal, and so the tape was sent to them. Unfortunately the workload associated with the Voyager encounter at Saturn made this effort impractical, and they never had a chance to try the detection. Subsequently, colleagues at Stanford University, working on Voyager Radio Science, offered to try their software on the same tape. This was done and the result was a verification that we had performed the task correctly and that the signal was indeed undetectable. It is particularly unfortunate that this close

encounter was a failure, for it excelled in every way; highest latitude, closest paths, both paths closest to the sun, and both spacecraft equipped for dual-frequency operation.

C. Results of the Third Close Encounter

The third was the only encounter from which usable recordings were recovered for both spacecraft. At the time, Pioneer 11 was being tracked continuously, so it was only necessary to obtain a short run from Pioneer Venus in order to obtain the pair. Because Pioneer Venus was once again operating with its high-gain antenna, a strong signal was received. It was readily visible in the spectral signal indicator, facilitating the radio tuning. As is depicted in Figure 4, both paths were fairly well away from the sun and so the scintillation was not too severe for a steady tracking.

The time required for plasma to travel from one path to the other, a distance of some 4.6 solar radii or about 3 million kilometers is summarized in Table 9. The time required for this transit would be about 4.5 hours, if the solar wind speed were only about 200 km/s. Estimates of the average speed vary from 100 to 400 km/s, Gosling et al., [1974] with even higher values being associated with eruptive prominences [Munro et al., 1979]. Also, as discussed earlier, these values represent only the minimum at the point where the plasma makes a perpendicular crossing of the radio path. At oblique angles, the travel distance and time delay would have different values, but it was hoped that outstanding and identifiable irregularities would propagate from one path to the next so that the transit delay could be established.

D. Graphical Representation of Signal Characteristics

Because Pioneer Saturn was tracked almost continuously with 64-m dishes, we have been able to obtain a high quality record lasting more than nine hours. It is fortunate that this long record exists, in view of a comparatively large distance between the Pioneer Venus and Pioneer Saturn radio paths. In contrast, for Pioneer Venus on this date we were able to obtain a record lasting only 100 minutes, and during about ten of these minutes the signal was rendered unusable because of a high Doppler rate, apparently caused by unfortunate programming of the local oscillator on the ground. In addition, the first 80 minutes of the Pioneer Saturn record preceded the beginning of the Pioneer Venus record and, while valuable as a basis for perception of pattern expectations, nevertheless this portion serves no purpose in the timing comparison since the plasma occupying the radio path cannot possibly have been observed during its passage through the Pioneer Venus path. With these restrictions on both paths, in the final analysis we have a 1.5-hour Pioneer Venus record to compare against an 8-hour Pioneer Saturn record that begins at the same time. Since pattern recognition requires an overlap of some 30 minutes, the maximum lag that could be detected with these data is about 7.5 hours.

There is no precedent for work of this type, and lacking experience we must turn to analysis and logic in an effort to find the most useful parameter with which to search for evidence that the same plasma passed through both paths. Fortunately, this plasma is quite turbulent and so constant changes occur in such parameters as the frequency, phase, scintillation index, and spectral appearance; in fact, almost any

parameter that characterizes the carrier signal of the radio waves undergoes changes due to the plasma if one measures that parameter with sufficient precision. Because changes constantly occur in everything, we must hope that some unusual coronal plasma change occurs during the recording session having a form that can be identified in measurements taken from both spacecraft.

After trials, we concluded that the optimum form of data in which to search for anomaly patterns is the spectrum of the signal across the entire band of possible spreading, displayed continuously as a function of time. This requires a three-dimensional display for which we have chosen the form depicted in Figure 7 in which data from both Pioneers are shown. The three dimensions (intensity, ordinate, and abscissa) represent power, frequency, and time, respectively. In the Pioneer Saturn record, broken into two strips at the point of a data loss at 1839 UT, the third harmonic is seen relatively faintly, with inverted phase because of the processing. The scallop pattern in frequency versus time is caused by DSN's attempt to maintain the signal of ever-changing frequency within a limited band by using a local oscillator that follows a frequency-versus-time profile of connected straight lines. The residual difference between the curve and the closely matched, connected straight lines is a scallop pattern as seen in Figure 7. The scallop is of tripled amplitude in the third harmonic and, because it is inverted and near the main trace, the separation between the main and the third is four times the actual frequency change.

Given the display of Figure 7, the challenging task is to locate a repetitive pattern between Parts (a) and (b). Two broad approaches to the detection of this lag are feasible; first, although much research is underway in computerized pattern recognition, nevertheless it remains true at present that the recognition of uniqueness in unexpected patterns is performed better by a human being than by any existing computerized approach. At the same time, we know that computers excel in such things as cross-correlation calculations that can detect the time lag between reproductions of identical patterns in two wave forms that are too subtle for human perception. In the comparison of Pioneer Venus and Pioneer Saturn records, both of these approaches were tried, but the greatest stress during our studies was placed on the human pattern-recognition approach; computers were used primarily to display data in different ways where pattern visibility would be enhanced through processing. The problem with computer correlation in this context is the one mentioned with respect to Figure 4(b). Some of the plasma moving outward from the sun will cross the paths at perpendicular incidence where the distance between paths is only $4.6 R_{\odot}$. Yet if we move five million kilometers along the radio path, then we find that the plasma flowing from the sun encounters the paths at about the same latitude and at a slightly increased distance from the sun, but the distance between the paths is now increased to $5 R_{\odot}$. If we move ten million kilometers along the radio path from the point of closest approach, then the distance between paths is increased to $6 R_{\odot}$. As was discussed earlier, events at the point of closest approach are favored because the plasma is most dense there. However the effect is not so overwhelming that other points along the path need not be considered.

In the first case where the intrapath distance is $5 R_{\odot}$, the heliocentric distance was about eight percent larger than that at closest approach so the density was about 85 percent of its value at the closest point. Even when the intrapath distance was $6 R_{\odot}$, the density was still 60 percent of that maximum value.

These distance variations have a strong effect on our expectations of the time durations that we expect to witness in the pattern lag from one path to the next. To the extent that the solar plasma flow is broad, so that the flow density outward over a broad range of latitudes and longitudes from the sun is roughly equal, we should expect to observe a simultaneous mixture of time lags varying by several tens of percent. Because the expected time lag is two or more hours, (or even less if a coronal transient from a large flare was in progress), then the lags observed simultaneously will vary over a matter of tens of minutes. Thus the pattern repetition from Pioneer Venus to Pioneer Saturn should show evidence of changing detail on a time scale less than ten minutes. This line of reasoning leads us to expect that the signature of the same plasma passing first through one path and then through the other path will be a broad repetition of patterns that are the same on time scales of ten minutes, but perhaps quite different on a time scale of one minute.

Another view can be stated, which will be valid in some cases. We know from white-light coronagraphs that the sun ejects narrow streams of plasma, subtending latitude ranges of a few degrees [e.g., Sheeley et al., 1980]. If such a narrow stream should happen to intersect the radio

path, and undergo temporal variation during the measurement, then the limited angular extent of the stream would preserve the fine time scale of the temporal variation. In this case, patterns might reoccur with fine detail preserved. However, we must recognize that this eventuality requires a stroke of good fortune in two respects: (1) the path must lie in such a thin stream and (2) a variation must occur during the 1.5 hours of Pioneer Venus recording.

Following the above criteria, the author has examined the data and found two locations where a potential match could be found. The second of the two matches is illustrated in Figure 8. It is significant that the first match was not attributable to plasma flow because the pattern on the Pioneer Saturn record preceded that on the Pioneer Venus record by some ten minutes, constituting a negative lag of the intended type. The fact that this first pattern match was at least of the same quality as the one depicted in Figure 8 gives emphasis to the fact that the latter should be considered at most suggestive. The broad frequency changes that match each other in the two records are not likely to be residual scallops arising from local oscillator straight-line fitting. There is little similarity and no relationship between the fits used for Pioneer Venus and those for Pioneer Saturn, since the former is orbiting Venus while the latter is on a steady course. On the positive side, however, we note that the alignment in Figure 8 shows a lag of three hours and seven minutes, which in turn indicates a corona plasma velocity of 280 km/s. Such a velocity is entirely consistent with the

present-day view of the corona at this distance from the sun [e.g., Woo and Armstrong, Figure 3, 1980]. With this match we have carried the human pattern-recognition approach to its limit, and should turn to comparison of the records by means of computer processes. This has not yet been done, but we present in Figure 9 a form of data that might serve as the basis for such computerization; a high-resolution spectrum showing fine detail of the Pioneer Saturn signal in the center of the matched region. This figure is one representation of a large two-dimensional table of numbers that is amenable to computer processing. A simpler search, and perhaps one that is less likely to succeed, would result if the data were processed into a form that produces a single-valued function of time. For one example, the scintillation index could be repeatedly calculated. Alternatively, the frequency of the peak of the spectrum could be determined as a function of time. One might also use frequency versus time as the basis for calculating the changes in electron content, and then seek correlations between the electron content records from Pioneer Saturn and Pioneer Venus.

VI RESULTS FROM MULTIPLE SPACECRAFT CORRELATIONS

Although the close encounters are disappointing, with two failures and one result of questionable value, there remains the more broadly based study of the entire northern coronal region, taking advantage of the presence of so many spacecraft. The value of the spacecraft, in this instance, lies in the service they provide as a basis for correlative study when combined with data from other investigators who examine the corona and the sun with Earth-bound instruments or with different spacecraft. The result of this phase of the experiment, in broad outline, is as follows:

- The Doppler noise measurement worked extremely well. Initial plots of the noise itself **seemed contaminated by radio-receiver** effects, but a subsequent plot of the ratio of two noise values (shown later) is likely to be most useful in correlative analysis.
- Attempts to measure the electron content using differential group delay from the Voyager spacecraft have failed apparently from inadequate calibration of the delays encountered in parts of the ground equipment. Unfortunately, 1979 was the last year during which this problem existed. By 1980, the same system worked well (P. B. Esposito, JPL, private communication).
- The small amount of tracking on the Voyagers and the loss of high-gain antenna on Pioneer Venus while it was near the sun had a major negative impact in limiting the total quantity and quality of data.
- For all participating spacecraft, the available data are limited to those periods during which the spacecraft was nearest the sun. Those who would collaborate on this observational interval should consult the spacecraft availability charts in Tables 1 through 8 before proceeding, since much of STIP Interval VII is

only sparsely observed. The tables provide hourly guidance but minute-by-minute coverage is not accurately depicted. For example, a continuous string of Ds extending over five consecutive hourly periods might mean that the record lasted only slightly more than three hours, but that it extended slightly into the first and fifth hour. Those collaborators who find the first and last hours of timing critical should contact us for greater detail.

VII SOURCE OF THE "DOPPLER NOISE"

As the signal from each spacecraft is received, its frequency is detected and the value is conveyed to a computer ten times per second. Based on trajectory predictions, the computer is equipped with the information and software necessary to compute the expected value of frequency at each of those ten times per second. The difference between the measured and expected frequency is computed, and is termed the "residual frequency."

Four types of Doppler noise are computed, but only two are used in this study and so only those two are described here. ("Low" and "High" rate noise are not used.) The "medium-low rate" noise is formed in a two-step process. First, 18 consecutive Doppler residuals are collected and a straight line is fit to these residuals in frequency-time space. The straight line then defines a Doppler noise value associated with the time of each sample. The differences between the samples and the straight line values is called the "detrended" residual Doppler noise. From the 18 detrended values, the root-mean-square (rms) value is computed. This procedure is repeated one hundred times, thus completing the processing of all the data acquired during a three-min period. Finally, the 100 rms values are averaged, and this is the medium-low rate Doppler noise.

The medium-high rate Doppler noise is derived from the same basic data. However, the procedure is different. First, ten of the original Doppler residuals are averaged. Each then represents one second of measurement. Eighteen of these one-s residuals are then fit by a

straight line, and the straight line values are subtracted leaving detrended one-s residuals. Ten such estimates are accumulated in a three-min period, and their average forms the medium-high rate Doppler noise.

These numbers were originally implemented to monitor ground tracking system performance, with the recognition that the short-term averages tend to indicate hardware condition whereas the longer-term averages are more useful for determining the state of the environment traversed by the radio signal [Renzetti and Berman, 1981]. With the permission of the latter authors, I present in Figure 10 a revealing comparison of Doppler noise and electron content as measured with the Viking spacecraft during a Solar Conjunction Interval. It can be seen that the Doppler noise is a moderately faithful reproduction of the electron content, since the two parameters remain proportional to one another within a factor of approximately two. The Doppler noise used in this figure was derived from an earlier algorithm than either of the two discussed above, but the parameter is however, fundamentally the same.

VIII DOPPLER NOISE RESULTS FOR ALL SPACECRAFT

Because this report constitutes the first publication outside JPL that describes the use of Doppler noise from U.S. spacecraft, I will comment on some of the procedural matters with the objective of providing aid to those who may wish to use this same parameter in the future. Some of this discussion will, therefore, not be of interest to those readers solely interested in the scientific outcome. Although the Doppler noise is easily computed and somewhat freely made available to scientific users, nevertheless it is conveyed to users in a form that requires much work and computer time for the recovery of data. A "universal" type of digital tape is created, intended to provide information of almost all types compacted in a single source. As a result, each individual value of Doppler noise can only be derived after a computer search through a large tabulation of numbers on the tape. So many parameters are kept on one tape that a modest amount of Doppler noise data requires a great deal of processing on many tapes.

Typical Doppler noise results are shown in Figure 11(a) and (b) which show the Doppler noise at the "medium-high" and "medium-low" rates. In addition, there is a value provided at a low rate and another at a high rate; I have examined a large body of such data and have concluded that they were not useful indicators of the state of corona plasma. In examining such data, bear in mind that such measurements can be obtained only while there is active radio communication between the spacecraft (Voyager 1 in this case) and one of the three DSN stations on the Earth. Each such station utilizes a very large paraboloid antenna and, because

of mechanical considerations and because of tropospheric refraction anomalies, an effort is made to avoid using these dishes at elevation angles near the horizontal. Thus each track of a spacecraft is not from horizon to horizon but rather it is from a few degrees after rise to a few degrees before a set. Exceptions are made when observing spacecraft at a time of maximum importance, such as a planetary encounter, but in the kind of routine operation that produces solar data in bulk, each station may typically run for an interval of ten hours or less. In Figure 11, this operational constraint can be seen as it affects the data continuity. The plots are accumulated from all stations around the world.

Doppler noise is no longer computed by the DSN because of a seeming lack of interest. I used it only for that work reported here, and it is said that I have been the only user outside JPL. Nevertheless, when the noise computation was removed from the routine operational computer programs at the DSN stations, it was said the software needed for reinstatement of the noise calculation would be maintained in readiness should a potential user express an interest in it.

As a first step in data processing, we produced plots such as those in Figure 11 for the entire STIP Interval. The results are much too voluminous to be presented here, comprising some 41 pages like that in the figure. We have created all the necessary plots and compared them to the known pattern of solar activity during the STIP Interval VII. An initial list of such activity is summarized in Table 10, which is an excerpt from Solar Maximum Year (SMY) Newsletter 80-1, having been originally provided by M. Dryer. When the entire body of medium-high and medium-low Doppler noise was compared to solar activity indexes of this type, little correlation was found between the noise level and the known activity.

One of the problems witnessed in the Doppler noise at both the rates appeared to be a susceptibility to variation attributable to conditions on the ground that are indistinguishable from similar variations due to conditions in space. At times, there are variations in the records from different ground receiving stations having characteristics that seem to indicate the cause was a difference between stations themselves. One such change occurs on Figure 11(a): on the morning of August 5, two short recordings each exhibit constancy throughout their length and yet they are at levels below and above that of the preceding and following records. It is evident that the lack of a trend for change exhibited during the recording periods is incompatible with these changes in level. Because the records exist somewhat more than 50 percent of the time, a geophysical interpretation requires that all changes be confined to the unmonitored periods by chance. This seems unlikely; as a result I have concluded that the level variations were caused by the fact that the segments of record are obtained from different stations, responding differently to an unchanging signal.

At about the time this problem was uncovered, investigators at JPL began using the ratio of the Doppler noise at different rates as a means for calculating the spectral signal index [Berman and Contreas, 1979]. To evaluate this approach we calculated the ratio of medium-high and medium-low noise, obtaining results exemplified by Figure 11(c). This step eliminated much of the problem previously encountered. One can see in Figure 11(c) that the station-to-station fluctuations seem to be eliminated. The two short records on the morning of August 5 exhibit trends that now fit in with the trends exhibited during the monitored intervals.

One could draw a single, continuously curved line through the ratio data, fitting all the segments together and still matching the curvature and slopes during the recording interval. This could not be done with the Doppler noise itself. It is apparent that the formation of the ratio discriminates in favor of the spectral index of geophysical variations and tends to eliminate effects attributable to the hardware or software in the ground receiving facilities.

Because Figure 11 represents slightly more than two percent of the data we have processed and displayed during this study, it is not feasible to present it all on the scale of Figure 11. To give the overall picture, we have compressed the time scale by a factor of ten, eliminated the Doppler noise, and presented only the ratio. With these abbreviations, Figure 12 summarizes all STIP Interval VII spacecraft observations. A great deal more Pioneer Saturn data exists, but as may be seen in Figure 4(a), that spacecraft was far out to the east before September. As an economy measure we have found it necessary to restrict our interest to the ten-day period depicted in Figure 12(a).

The Pioneer Venus observations in Figure 12(b) give graphic evidence of the impact of the Pioneer Saturn tracking interval. In preparation for the Saturn encounter on September 1, Pioneer tracking was reduced to a short period of DSN dish overlap time beginning on August 18. Furthermore, the quality of the data suffered immensely when the high-gain antenna was disabled. These matters are most unfortunate since Pioneer Venus was the only spacecraft moving eastward during the interval.

The Voyagers produced a great deal of data, largely as a consequence of the vitality of the Radio Science Team and the Radio Science Data Team (at JPL) associated with that project. Independent studies of the solar conjunction, not directly related to the STIP Interval VII, were being planned by Professor G. L. Tyler of the Radio Science Team with the result that these measurements have been extended over a wider range of solar elongations than that provided by the Pioneer spacecraft. In addition, by good fortune the Doppler noise data for both Voyagers was accumulated in a single digital magnetic tape (Conteas, private communication, 1979) thereby saving much time and effort and doubtlessly contributing to the volume of the data available for this study.

In the assessment of the scientific implications of the variations in the ratios, one must be guided by the relative positions of the spacecraft in the visible sky. This is summarized in Figure 13 for the central 10° of view; for earlier and later days, particularly with reference to the Voyager spacecraft, most of the requirements for correlative data analysis can probably be met by extrapolations from this figure. The angular rates are virtually unchanging and the angle above the ecliptic is nearly constant. It is only for Pioneer Venus that the ecliptic angle changes noticeably, but an accurate extrapolation is feasible and in any case one can use the ephemeris of Venus if greater accuracy is required.

IX OTHER DATA OF VALUE IN CORRELATIVE STUDIES

To provide a basis for correlative studies among other experimenters, a brief mention will be made of the data which are known to exist concerning conditions in the northern corona in this time interval. No attempt will be made to list those sources of data which are available on a regular schedule and which are well known.

An almost ideal collaborative experiment was performed by the Radio Astronomical Laboratory of the Lebedev Physical Institute. Under principal investigator V. I. Vlasov, a program of daily measurements of interplanetary scintillation was undertaken. Throughout a region in the sky of some $70^\circ \times 170^\circ$, a selected group of about 150 stars was observed daily for about 1.5 minutes each. The program began August 8 and lasted through October 14, so it had excellent overlap with STIP Interval VII. For each such observation, measured at 102.5 MHz, the scintillation index was calculated, plotted on a chart of the heavens, and then contour intervals were fitted. Along the way several allowances had to be made so that such influences as the dimensions of the structure of the solar radio source would not influence the final result. Unfortunately, at the time of this writing, the only descriptive document is a preprint in the Russian language (available from the Lebedev Institute). Previous similar work by the same author was published in a major Soviet journal [Vlasov, 1979].

In an effort to draw from this massive work some evidence of use in interpreting the spacecraft measurements, I studied the daily contour charts at length. Seeing little pattern in their raw form as presented in line drawings, I drew different shades of color over the charts to

represent the various contour levels and then assembled the charts in a collated book so that one could flip rapidly through them, seeing the change from chart to chart. In such a flip book, the sun and ecliptic plane remain stationary while the observed region of the sky slowly moves upward toward the north northeast. Still seeing no pattern, I assembled the color images in a motion picture and then watched the result with an analytical stop-action projector. Even with this ultimate treatment, I regret to say that I could see no evidence that active regions persisted and corotated with the sun. Of course, such pattern recognition is intensely subjective, so it is to be hoped that others will find it possible to perceive and to demonstrate the existence of meaningful patterns in these data. The study is so directly relevant to the concerns of STIP Interval VII that factual conclusions would surely be valuable.

Another new development from the Soviet Union appears in a brief letter from G. Zastenker (private communication, 1980) giving a preliminary notice that Venera 11 observed solar wind disturbances in August and September. Zastenker provided a sketch of the spacecraft trajectories marked to show the locations at which the shocks were detected. From this I performed a graphical interpolation to determine that the dates were August 3, 10, 24, and 31 and September 12. With reference to the overall data availability depicted in Figure 12, these events are well timed. We hope that these same events may be seen by other means so that a correlation is productive.

One of the most prolific authors on the subject of scintillation of spacecraft signals is Richard Woo of JPL. He had independently studied the scintillation of signals from Pioneer Saturn and the Voyagers during STIP Interval VII and thus far has published two papers on the subject. In the second of these, which is the one most accessible to readers, Woo and Armstrong [1981] have conducted a detailed study of fluctuations in the carrier signal from Voyager 1 on August 18. Unfortunately this paper became available too late for the determination for any correlations to the Voyager 1 records we have obtained.

In another paper that is perhaps more relevant to the subject of this report, Woo and Armstrong [1980] compared Helios and Pioneer Saturn measurements during STIP Interval VII, reporting these results as an invited paper at the "Workshop on Shock Waves in the Solar Corona" at Smolenice, Czechoslovakia. They emphasized a Helios event on November 16, well past STIP Interval VII, but more importantly they provided an excellent summary of the Pioneer Saturn spectrum bandwidth covering approximately 80 percent of the time from September 6 through 14. This spectrum bandwidth plot, copied with their kind permission as Figure 14, provides an excellent extension to our Doppler noise graph in Figure 12(a), carrying it past the point of minimum heliocentric distance on for another 4.5 days. We were particularly gratified by the close correspondence between these bandwidth fluctuations on September 8 and the same events seen in the medium-high Doppler noise. Each maximum of bandwidth was matched by a maximum of noise and by a minimum of the derived ratio. Time axis compression in Figure 12 has masked this correspondence, but it is clear when one examines the Pioneer Saturn noise on a time scale like that in Figure 11.

Using an Earth-orbiting coronagraph in the Solwind satellite, a large coronal mass ejection was observed near the solar north pole on September 27, 1979 [Sheeley, et al., 1980]. Unfortunately this occurred after the Voyager and Pioneer spacecraft had cleared the area; nevertheless, the outburst of dense plasma may be of correlative value to others working on STIP Interval VII.

Dr. Randolph Levine of the Harvard College Observatory Center for Astrophysics expressed an interest in computing potential field models near the sun and tentatively offered to produce such information based upon solar magnetograph data during STIP Interval VII [Levine, private communication, 1980]. He suggests that such computations based upon the records presently available at the Stanford Solar Observatory would "add a significant dimension to the interpretation of radio data."

From the Vikram Space Physics Center of A.P.S. University, Rewa, India, I received an expression of interest in collaborative data analysis from Dr. Sant P. Agrawal. He and his group operate a super neutron monitor to record cosmic ray intensity variations near the equator. His group is particularly interested in solar terrestrial relationships as they relate to the interplanetary variables.

From J. C. Henoux, head of the Solar Department of the Solar and Planetary Astronomy Department at the Observatory of Paris, a brief letter was received suggesting that their daily spectraheliograms in H_{α} , K_3 , and K_{1v} would be obtained during STIP Interval VII. Clearly this group will be well equipped with data for potential correlations.

Also from the Observatory of Paris but from the Astrophysics Section, Monique Pick wrote to point out that the Nancay radio heliograph would observe the sun at 169 MHz during all of August and September. The main characteristics of the instrument and some preliminary results were published by the Radio Heliograph Group [1977].

Dr. Michael Bird wrote from the Radio Astronomical Institute of the University of Bonn concerning his plans to observe Jupiter at 11 cm, virtually the same frequency as that of the telemetry signal from the Pioneer spacecraft. Dr. Bird had modified an early version of the drawing which is presented here as Figure 13. He added the location of Jupiter during STIP Interval VII, showing that it moved through the same area from left to right slightly closer to the sun than Voyager 1 and about two days behind it.

From the Jet Propulsion Laboratory, in addition to Dr. Woo, several other investigators have expressed an interest in collaborating. Because of their close association with the continuing efforts to improve interplanetary telecommunications, C. Stelzried, B. Seidel, and A. Berman have access to much spacecraft data pertaining to the passage of radio signals by the sun. They have a continuing interest in acquiring a better understanding of the events in the corona insofar as they may be used as a basis for improving the telecommunications by radio signals making a passage through that disturbed region.

A few persons have written to express an interest in collaborating, but without giving a specific suggestion as to the form of data that they might be able to contribute to any such collaboration. One of my

objectives in writing this report is to provide a source of information for those who would like to participate in a joint study of STIP Interval VII. I will make a brief mention of these other interested parties.

From the observatory at the University of Nice, Jean-Claude Fernandez expressed an interest, and he also mentioned that his colleagues G. Reinisch and C. Montes would like to participate.

Joseph Hollweg of the University of New Hampshire suggested an interest in making Faraday rotation observations by using the participating spacecraft, but unfortunately the signals from the spacecraft are circularly polarized. Furthermore, at the time of the parade of spacecraft, the DSN receivers were unable to make a measurement of the comparative strength of orthogonal linear or counter-rotating circular polarizations. As a result, Dr. Hollweg's concept could not be implemented. Now the ground receivers are equipped to make the measurement, and it would be possible provided that the transmitted signal had some degree of elliptical polarization included within the signal. I have investigated this matter briefly through liaison with key JPL designers, and it is the present view (though not thoroughly researched) that the Voyager signals are so nearly circular in polarization that the residual linear component is not strong enough to be detected, particularly near the time of a Superior Conjunction when noise is enhanced.

Henrik Lundstedt, a Swedish scientist, has a particular interest in the subject of coronal holes, high-speed plasma streams, and the interaction with the atmosphere of Earth. He found that the STIP Interval collaboration meshed with his interests.

Mr. H. Washimi from the University of Nagoya, Research Institute of Atmospherics, has been performing interplanetary scintillation observations [e.g., Washimi et al., 1980]. This group has expertise in the acquisition of scintillation information that is essentially like the Doppler noise displayed in Figure 12, and in the processes whereby such observations are related to solar and solar corona observations obtained elsewhere.

X CONCLUSIONS

STIP Interval VII was established to capitalize upon the chance meeting of four spacecraft that appeared to be beyond the northern solar corona in late August and early September, 1979. Although a large and sustained effort was mounted to acquire a great deal of diverse data from these spacecraft, several sources of difficulty prevented an optimum operation with the result that many of the opportunities for observation were lost. In particular, the second close encounter, which showed great promise, was rendered virtually useless when the high-gain antenna on Pioneer Venus was disconnected. The broad-base experiment to capitalize on the presence of so many spacecraft in a confined space was hindered by two main factors: the need for high priority on Pioneer Saturn observations because the Saturn encounter occurred at the midpoint of STIP Interval VII, and the inability of the Voyager spacecraft to yield values of electron content, which would have provided valuable information. Despite these shortcomings, there was, nevertheless, a great deal of Doppler noise acquired by all four spacecraft and in addition Woo and Armstrong have published signal spectrum width measurements that effectively extend the Pioneer Saturn data that I have collected. Thus, while the loss of content observations is disappointing, the observational interval did yield a large body of data that reveals the state of the corona and that should be useful in correlative studies when joined with other data.

The one close encounter that did work, involving Pioneer Venus aligned with Pioneer Saturn, may provide a value of solar wind speed,

but the result is not unambiguous. Although a match that has been found yields a value of plasma velocity that is in the center of the expected range of values, nevertheless the fit of Pioneer Venus to Pioneer Saturn data characteristics may be fortuitous.

As an aid to those who would have an interest in correlative studies during STIP Interval VII, an effort was made in the closing pages to mention all those who have suggested that they have data they would like to correlate, and also the several correspondents who have written to express a more general interest in participating. Additionally, tabulations have been provided to guide potential collaborators to the times of data availability from all four of the key spacecraft.

ACKNOWLEDGMENTS

The parade of spacecraft was widely accepted by the scientific community as a unique observational opportunity, but considerable reluctance was encountered when I began the long process of arranging for changes in the spacecraft operation schedule and the schedule of the Deep Space Network receivers. The partial success was in no small part due the Voyager-related efforts of Dwight P. Holmes and Peter E. Doms at the Jet Propulsion Laboratory and to the Pioneer-related efforts of Richard O. Fimmel and Robert W. Jackson of NASA/Ames Research Center. From NASA Headquarters, modest Voyager support was obtained from Milton A. Mitz and Pioneer support from Robert E. Murphy. The members of the Voyager Radio Science Team, and particularly the leader G. Leonard Tyler, lent their considerable prestige to this mission. Once the data were finally available at SRI International, important assistance was rendered to the author by Bruce Craig and Bernice T. Bumbaca. This study was supported (in part) by the Air Force Geophysics Laboratory, project order ESD 9-0952 and ESD 0-0938 through NOAA purchase order NA79RAC00106.

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LIST OF TABLES

- 1 The Week Beginning August 03, 1979
- 2 The Week Beginning August 10, 1979
- 3 The Week Beginning August 17, 1979
- 4 The Week Beginning August 24, 1979
- 5 The Week Beginning August 31, 1979
- 6 The Week Beginning September 7, 1979
- 7 The Week Beginning September 14, 1979
- 8 The Week Beginning September 21, 1979
- 9 Range of Speeds Encompassed
- 10 Solar Events During STIP Interval VII

TABLE 1. THE WEEK BEGINNING AUGUST 3, 1979

UNIVERSAL TIME OF DAY													
S/C	AM					PM							
	M					N							M
	0	2	4	6	8	10	NOON	2	4	6	8	10	12
AUGUST 3 - DAY 215													
PV													
PS													
V1	D	D	D	D	D	D	D	D	D	D	D	D	D
V2							D	D	D	D	D	D	D
AUGUST 4 - DAY 216													
PV													L
PS													
V1	D	D	D	D	D	D	D	D	D	D	D	D	D
V2							D	D	D	D	D	D	D
AUGUST 5 - DAY 217													
PV													L L
PS													
V1	D	D	D	D	D	D	D	D	D	D	D	D	D
V2							D	D	D	D	D	D	D
AUGUST 6 - DAY 218													
PV													L L
PS													
V1					D	D	D	D	D	D	D	D	D
V2	D												
AUGUST 7 - DAY 219													
PV													L L
PS													
V1				D	D	D	D	D	D	D	D	D	D
V2							D	D	D	D	D	D	D
AUGUST 8 - DAY 220													
PV													L L L
PS													
V1	D	D	D	D	D	D	D	D	D	D	D	D	D
V2	D	D	D	D	D	D	D	D	D	D	D	D	D
AUGUST 9 - DAY 221													
PV													
PS													
V1	D	D	D	D	D	D	D	D	D	D	D	D	D
V2	D	D	D	D	D	D	D	D	D	D	D	D	D

(PV = Pioneer Venus, PS = Pioneer 11 = Pioneer Saturn, VI = Voyager 1, and V2 = Voyager 2)

TABLE 2. THE WEEK BEGINNING AUGUST 10, 1979

UNIVERSAL TIME OF DAY																
S/C	AM								PM							
	M								N						M	
	0	2	4	6	8	10		NOON	2	4	6	8	10		12	
AUGUST 10 - DAY 222																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D	D	D	D	D	D									
V2		D	DL	DL	DL	DL					DL	DL	DL	DL		
AUGUST 11 - DAY 223																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D	D	D	D	D	D									
V2		DL	DL	DL	DL	DL					DL	DL	DL	DL		
AUGUST 12 - DAY 224																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D	D	D	D	D	D									
V2		DL	DL	DL	DL	DL					DL	DL	DL	DL		
AUGUST 13 - DAY 225																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D	D	D	D	D	D									
V2	D	DL	DL	DL	DL	DL	D	D	D	D	DL	DL	DL	DL	D	
AUGUST 14 - DAY 226																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D		D	D	D	D									
V2	D	DL	DL	DL	DL	DL	D	D	D	D	DL	DL	DL	DL	D	
AUGUST 15 - DAY 227																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DLDL	
PS																
V1	D	D	D	D	D	D	D							D	D	
V2	D	DL	DL	DL	DL	DL					DL	DL	DL	DL	D	
AUGUST 16 - DAY 228																
PV	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	
PS									L	L	L	L				
V1																
V2	D	DL	DL	DL	DL	DL	D	D	D	D	D	D	D	D	DL	

TABLE 3. THE WEEK BEGINNING AUGUST 17, 1979

UNIVERSAL TIME OF DAY													
S/C	AM					PM							
	M					N					M		
	0	2	4	6	8	10	NOON	2	4	6	8	10	12
AUGUST 17 - DAY 229													
PV	D	D	D	D	D	D	D	D	D	D	D	D	DLDL
PS													
V1													
V2										DLDL	DLDL		
AUGUST 18 - DAY 230													
PV	D	D	D										D D
PS													
V1										DLDL	DLDL		
V2													
AUGUST 19 - DAY 231													
PV	D	D											D D D
PS													
V1										DLDL	DLDL		
V2													
AUGUST 20 - DAY 232													
PV	D	D											D D D
PS													
V1										DLDL	DLDL		
V2													
AUGUST 21 - DAY 233													
PV	D	D											D
PS													
V1										DLDL	DLDL		
V2													
AUGUST 22 - DAY 234													
PV	D	D											D
PS													
V1										DLDL	DLDL		
V2													
AUGUST 23 - DAY 235													
PV										DLDL			
PS	L												
V1										DLDL	DLDL		
V2												D D D	

TABLE 4. THE WEEK BEGINNING AUGUST 24, 1979

UNIVERSAL TIME OF DAY													
S/C	AM					PM							
	M					N							M
	0	2	4	6	8	10	NOON	2	4	6	8	10	12
AUGUST 24 - DAY 236													
PV	D												
PS													
V1										DLDLDLDL			
V2					D					D D		D D	
AUGUST 25 - DAY 237													
PV										D D			
PS													
V1												DLDLDLDL	
V2			D D D D							D D D D D D D D D D			
AUGUST 26 - DAY 238													
PV										D			
PS													
V1	DL											DLDLDLDL	
V2	D D D D D D D									D D	D		
AUGUST 27 - DAY 239													
PV										D D			
PS													
V1	DL												
V2										D D D			
AUGUST 28 - DAY 240													
PV										D			
PS													
V1													
V2												D D	
AUGUST 29 - DAY 241													
PV										D			
PS													
V1													
V2	D D									D D D D D D D D D D			
AUGUST 30 - DAY 242													
PV										D D	D D		
PS													
V1		D		D								D D	
V2	D									D D D D D D D D D D			

TABLE 5. THE WEEK BEGINNING AUGUST 31, 1979

UNIVERSAL TIME OF DAY													
S/C	AM					PM							
	M					N					M		
	0	2	4	6	8	10	NOON	2	4	6	8	10	12
AUGUST 31 - DAY 243													
PV												D	D
PS													
V1	D												D
V2	DL												D
SEPTEMBER 1 - DAY 244													
PV													D
PS													D
V1	D	D	D	D	D	D							D
V2	D												D
SEPTEMBER 2 - DAY 245													
PV	D												
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D
V2	DL												D
SEPTEMBER 3 - DAY 246													
PV													D
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D
V2	D												D
SEPTEMBER 4 - DAY 247													
PV													D
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D
V2													D
SEPTEMBER 5 - DAY 248													
PV													D
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D
V2	D												D
SEPTEMBER 6 - DAY 249													
PV													D
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D
V2	D												D

TABLE 6. THE WEEK BEGINNING SEPTEMBER 7, 1979

UNIVERSAL TIME OF DAY													
S/C	AM					PM							
	M					N					M		
	0	2	4	6	8	10	NOON	2	4	6	8	10	12
SEPTEMBER 7 - DAY 250													
PV										D D		D D	
PS	D L D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D D
V2	D							D D					
SEPTEMBER 8 - DAY 251													
PV										D		D D	
PS	D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D							D D
V2													
SEPTEMBER 9 - DAY 252													
PV										D D D D			
PS	D L D	D	D	D	D	D	D	D	D	D	D	D	D
V1	D	D	D	D	D	D				D D D D	D D D D	D D D D	
V2													
SEPTEMBER 10 - DAY 253													
PV										D D D D D		D D	
PS	D	D	D	D	D						L L L L L L		
V1	D	D				D D D					D D D D D D D D D		
V2												D D D	
SEPTEMBER 11 - DAY 254													
PV													
PS													
V1	D									D D D D D D D D D D			
V2	D	D	D	D	D		D D D	D D D				D D D	
SEPTEMBER 12 - DAY 255													
PV													
PS													
V1	D					D D D D D D D D D D						D	
V2	D	D						D D D		D D D D D D D			
SEPTEMBER 13 - DAY 256													
PV													
PS											L L L L L		
V1	D	D	D	D	D	D							
V2	D							D D D D D D D D				D D D	

TABLE 7. THE WEEK BEGINNING SEPTEMBER 14, 1979

UNIVERSAL TIME OF DAY																							
S/C	AM										PM												
M										N				M									
0	2	4	6	8	10	NOON	2	4	6	8	10	12											
SEPTEMBER 14 - DAY 257																							
PV																							
PS																							
V1																							
V2	D	D		D	D		D	D	D	D	D	D	D	D									
SEPTEMBER 15 - DAY 258																							
PV																							
PS																							
V1																							
V2																							
SEPTEMBER 16 - DAY 259																							
PV																							
PS																							
V1																							
V2																							
SEPTEMBER 17 - DAY 260																							
PV																							
PS																							
V1																							
V2													D	D	D	D							
SEPTEMBER 18 - DAY 261																							
PV																							
PS																							
V1																							
V2	D	D	D	D	D	D		D	D	D	D	D	D	D	D	D	D						
SEPTEMBER 19 - DAY 262																							
PV																							
PS																							
V1																							
V2	D	D	D	D	D	D		D	D	D	D	D	D	D	D	D	D						
SEPTEMBER 20 - DAY 263																							
PV																							
PS																							
V1																							
V2	D	D	D	D	D	D									D	D	D	D	D	D	D	D	D

TABLE 8. THE WEEK BEGINNING SEPTEMBER 21, 1979

UNIVERSAL TIME OF DAY													
S/C													
	M					AM					N		PM
	0	2	4	6	8	10	NOON	2	4	6	8	10	M
SEPTEMBER 21 - DAY 264													
PV													
PS													
V1													
V2													
SEPTEMBER 22 - DAY 265													
PV													
PS													
V1													
V2													
SEPTEMBER 23 - DAY 266													
PV													
PS													
V1													
V2													
SEPTEMBER 24 - DAY 267													
PV													
PS													
V1													
V2													
SEPTEMBER 25 - DAY 268													
PV													
PS													
V1													
V2													
SEPTEMBER 26 - DAY 269													
PV													
PS													
V1													
V2													
SEPTEMBER 27 - DAY 270													
PV													
PS													
V1													
V2													

TABLE 9. RANGE OF SPEEDS ENCOMPASSED

Lag (min)	Speed (km/s)
130	406
140	378
150	353
160	331
170	311
180	294
190	278
200	265
220	240
240	220
260	203
280	189
300	176
330	160
360	147
390	136
420	125
450	118

TABLE 10. SOLAR EVENTS DURING STIP INTERVAL VII *

AUGUST 1979

14/1243 UT: an M3/1b flare began in region 1929 (McMath 16224); S22E73; Type IV; >5900 flux units at 2700 MHz.

18/1403 UT: X6/1b flare began in region 1943 (McMath 16239); N10E90; same region that produced flares on 20, 21, 23 and 25 August.

19/0850 UT: energetic protons (>10 MeV) exceeded proton event criterion (10/cm sq/s/sr); a peak proton flux of 450/cm sq/s/sr occurred at 0830 UT on 20 August.

20/0906 UT: X5/2b flare began in region 1943 (McMath 16239); N05E76; Type II; >10 MeV proton flux peaked a second time at 1700 UT at 410/cm sq/s/sr; maximum of PCA was 4.4 dB at 20/1715 UT.

21/0145 UT: M2/Sb flare began in region 1943 (McMath 16239); N07E68.

22/2353 UT: Cb/1a flare began in McMath region 1645; S19E73; Type II.

23/1242 UT: M2/1b flare began in region 1943 (McMath 16239); N07E79.

23/1943 UT: M1/1b flare began in region 1943 (McMath 16239); N05W01.

26/0130 UT: M2/2b flare began in region 1946 (McMath 16243); S14W57; Type II at 80 and 160 MHz.

26/1638 UT: X2/2b flare began in region 1943 (McMath 16239); N05W09.

19/0459 UT: see at Earth followed by major magnetic storm (A index at Fredericksburg, Virginia, reached 44; the largest K value at Fredericksburg was 6).

SEPTEMBER 1979

01/2329 UT: M2/1b flare began in region 1966 (McMath 16267); S20E66; Type II.

03/0423 UT: M1/1b flare began in region 1966 (McMath 16267); S19E55; Types II and IV.

07/0633 UT: C4/Sb flare began in region 1966 (McMath 16267); S16W05; Type II.

08/0643 UT: M2/Sb flare began in region 1971 (McMath 16271); S221W78.

10/0512 UT: M1/Sb flare began in region 1966 (McMath 16267); S18W45; Type II.

14/0652 UT: X2/spray erupted from region 1994 (McMath 16298); N10E90; Types II and IV.

16/0100 UT: X2/surge erupted from region 1994 (McMath 16298); N10E90; Type II.

16/0930 UT: X4/2b flare began in region 1994 (McMath 16298); N00E80.

* excerpt from Solar Maximum Year Newsletter 80-1

FIGURE CAPTIONS

- FIGURE 1 An illustration of the concept that long-path interplanetary signals may be useful for remote sensing in the corona.
- FIGURE 2 The radial alignment of two signal paths on August 17, 1979.
- FIGURE 3 The second radial alignment; the closest encounter of the three.
- FIGURE 4 The third and last radial alignment was much like the first except the signals were much weaker.
- FIGURE 5 Positions of six spacecraft relative to the sun as seen from Earth.
- FIGURE 6 Elongation vs time of the two Helios spacecraft. (Elongation is the angle between the object and the sun as measured at Earth.)
- FIGURE 7 Spectra obtained during the third encounter.
- FIGURE 8 Enlarged spectra, illustrating a possible pattern repetition between the two Pioneers.
- FIGURE 9 A highly detailed record of the spectrum from Pioneer Saturn.
- FIGURE 10 Concurrent measurements of Viking Doppler noise and columnar electron content.
- FIGURE 11 A detailed record of Doppler noise at two rates together with their ratio.
- FIGURE 12 The Doppler noise ratio throughout all of STIP Interval VII.

FIGURE 13 The relative positions of the four key spacecraft during those times when Doppler noise is available.

FIGURE 14 Spectral broadening of the Pioneer Saturn signal, effectively extending the period of observation depicted in Figure 12(a).

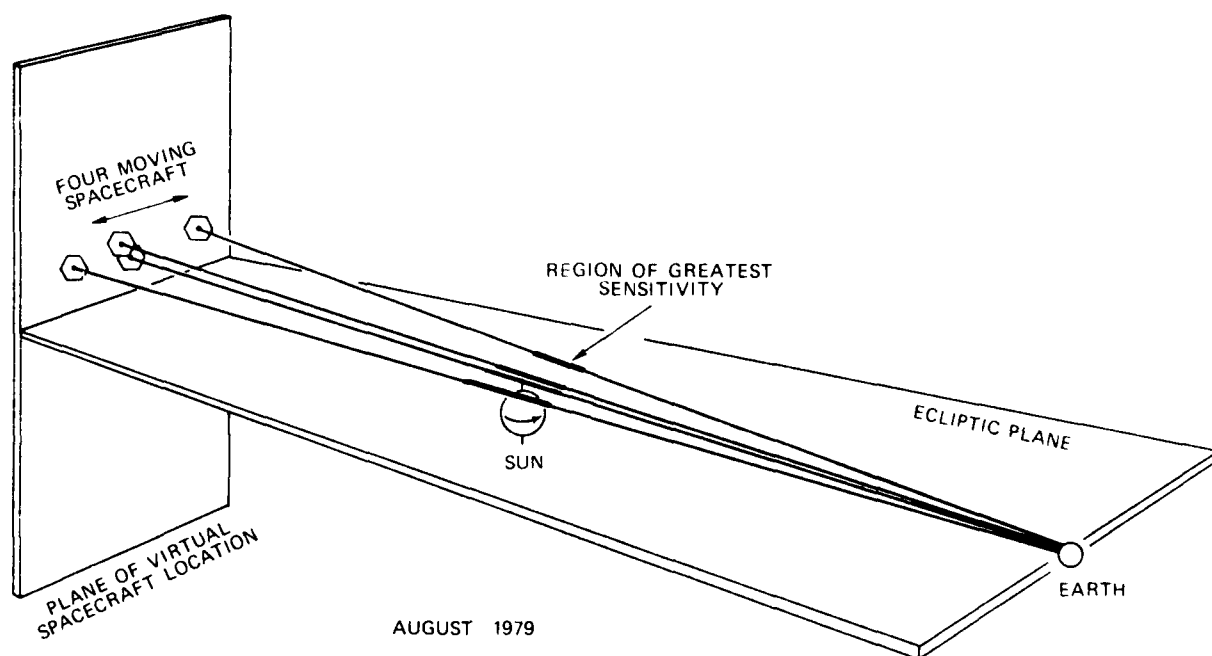


Figure 1

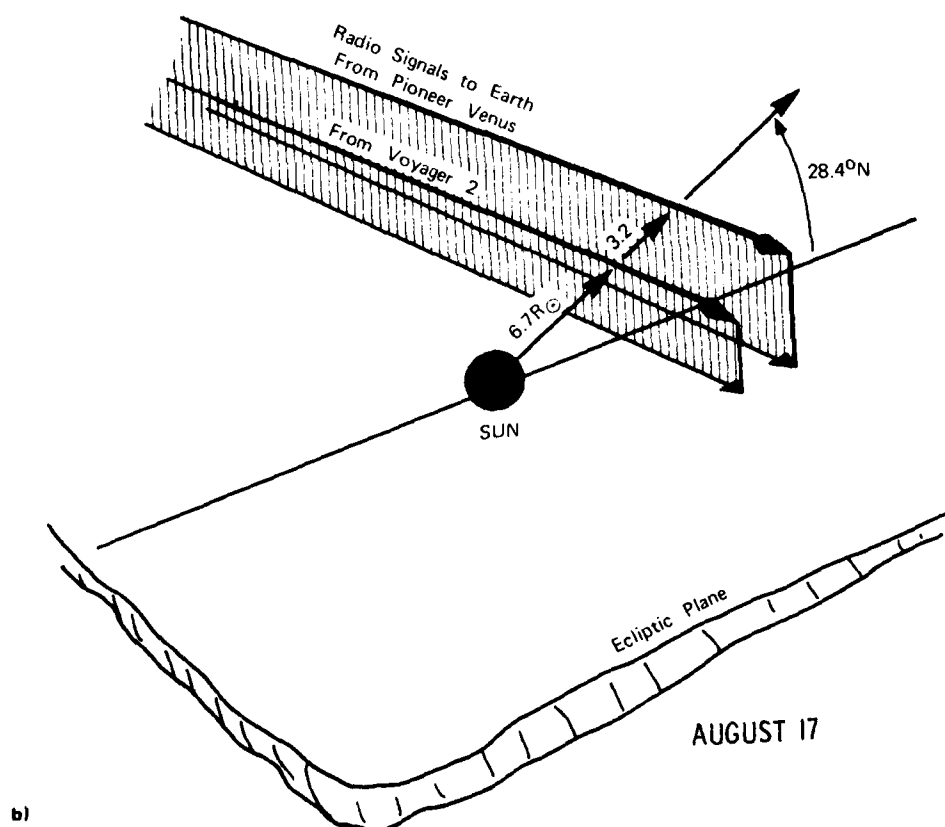
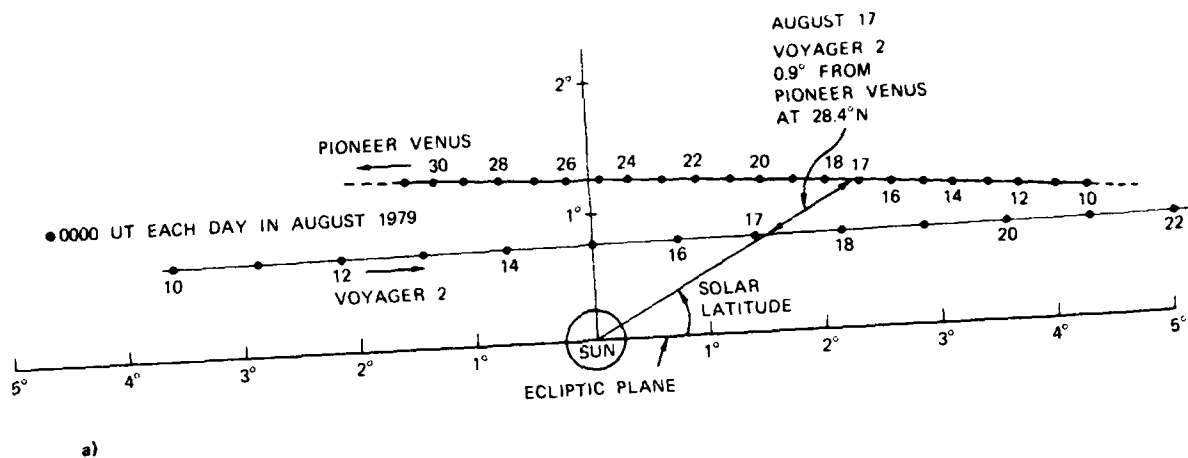
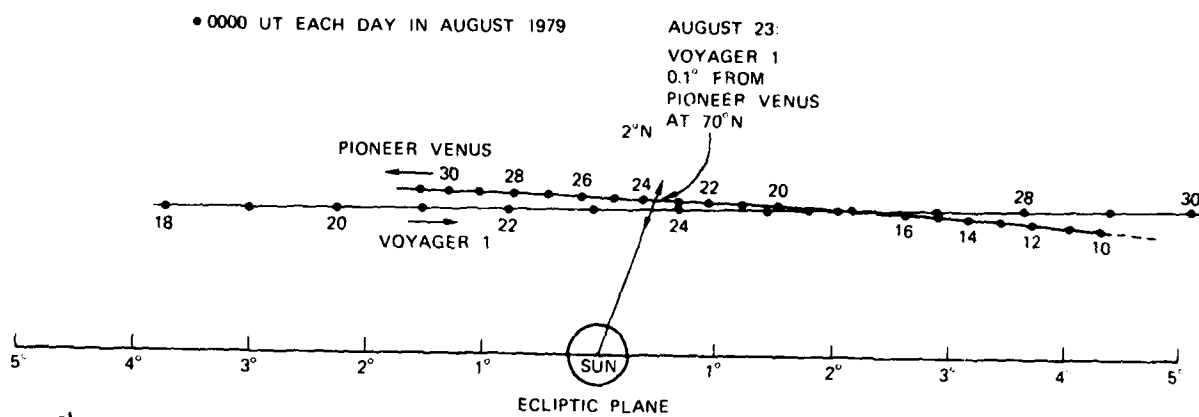
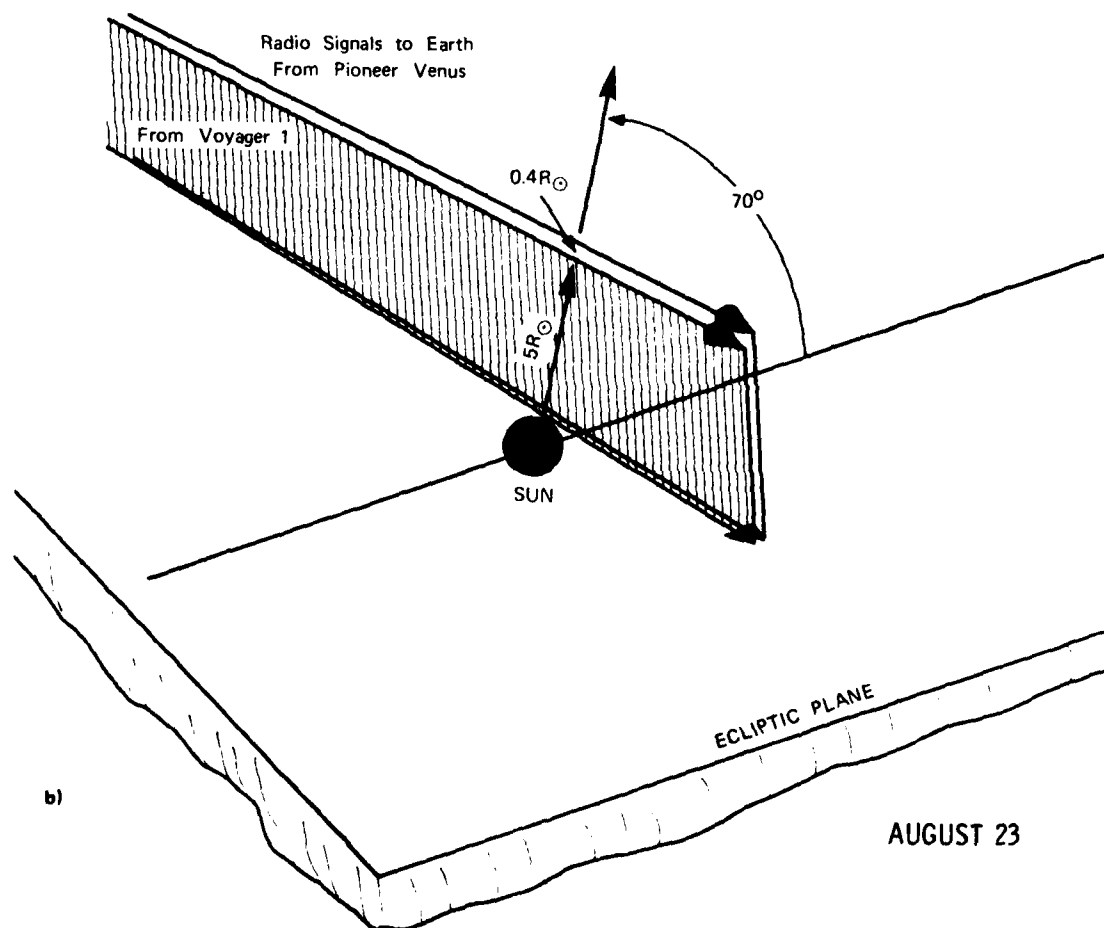


Figure 2

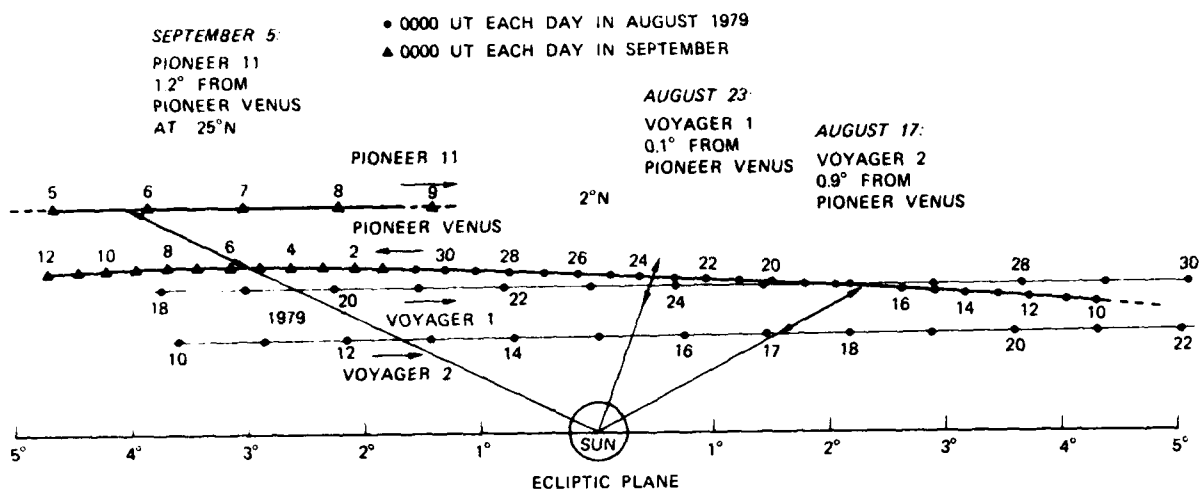


a)

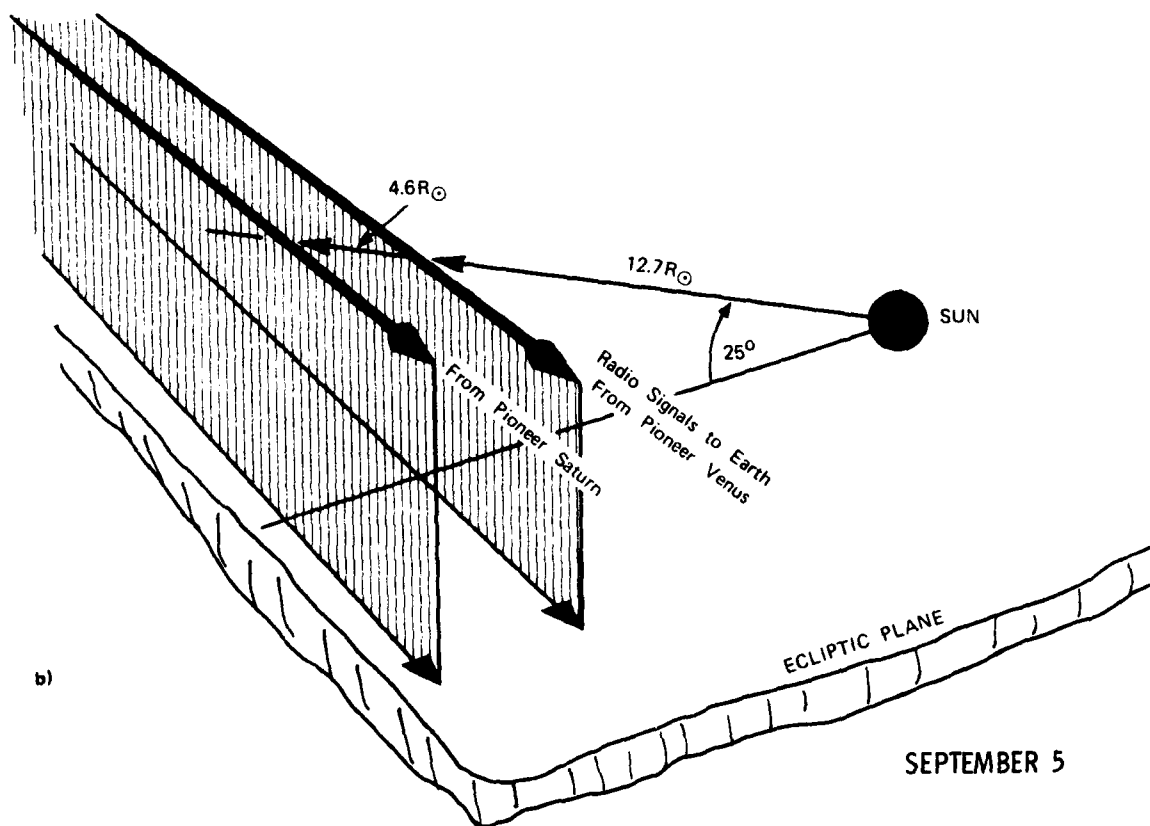


b)

Figure 3



a)



b)

Figure 4

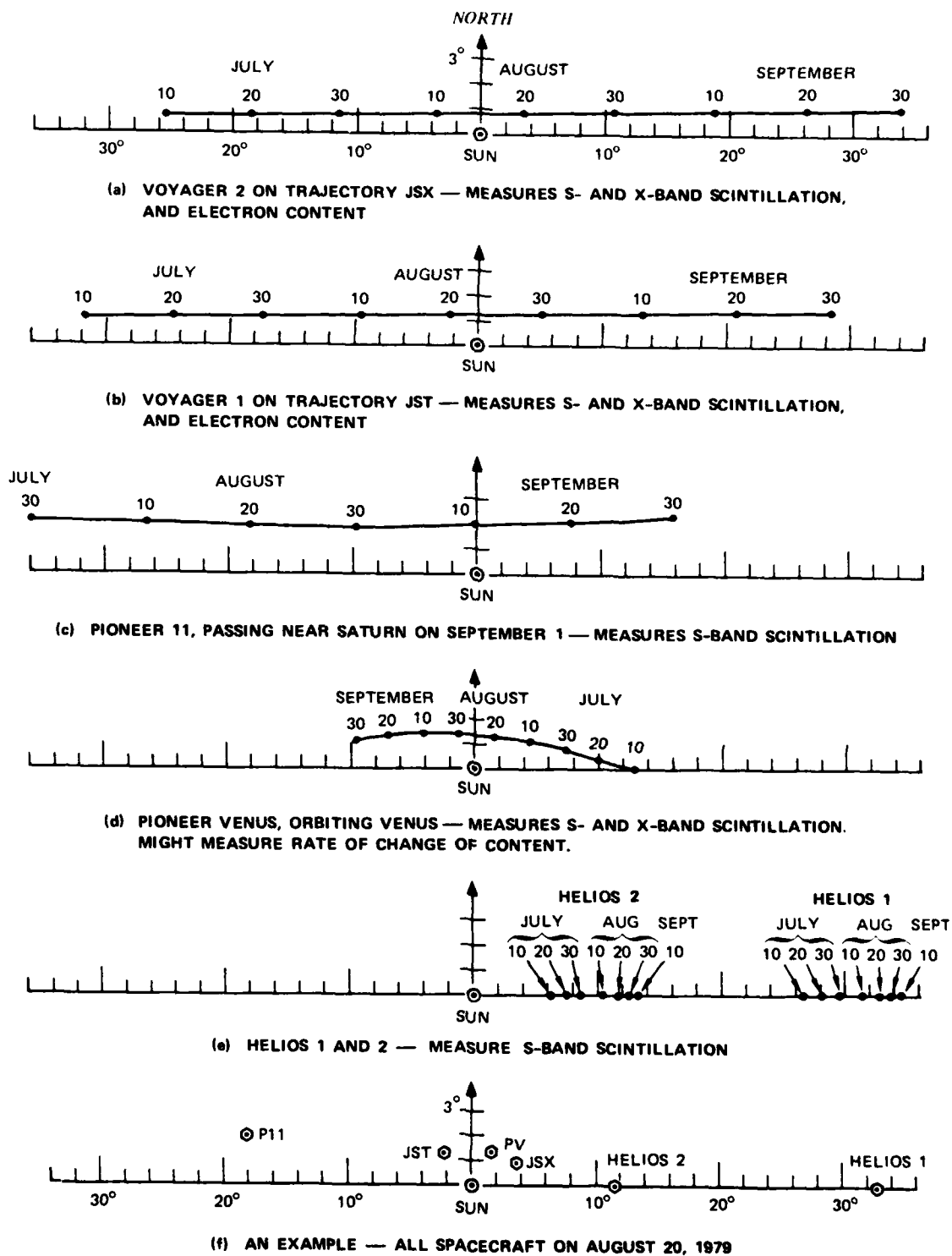


Figure 5

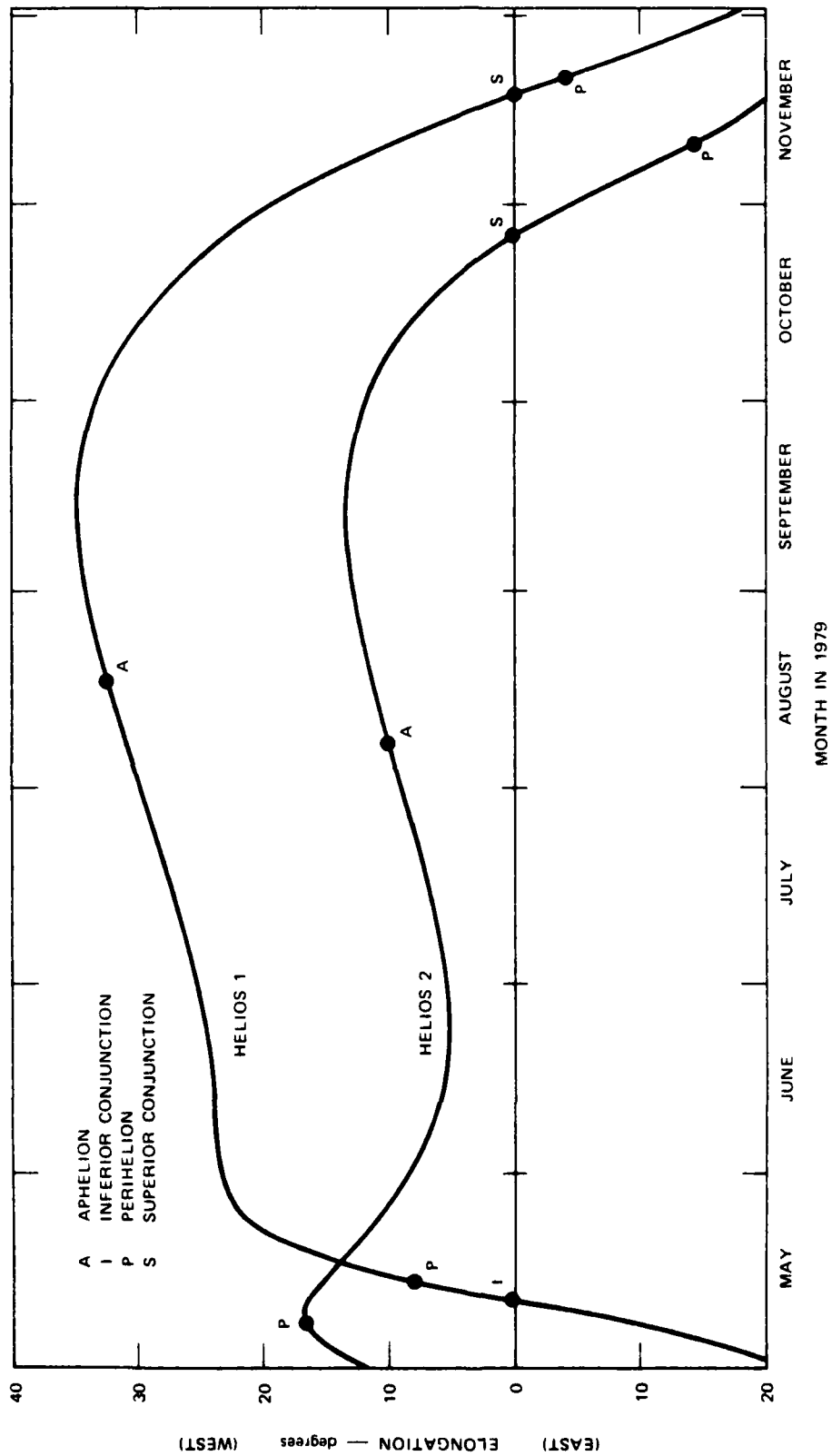


Figure 6

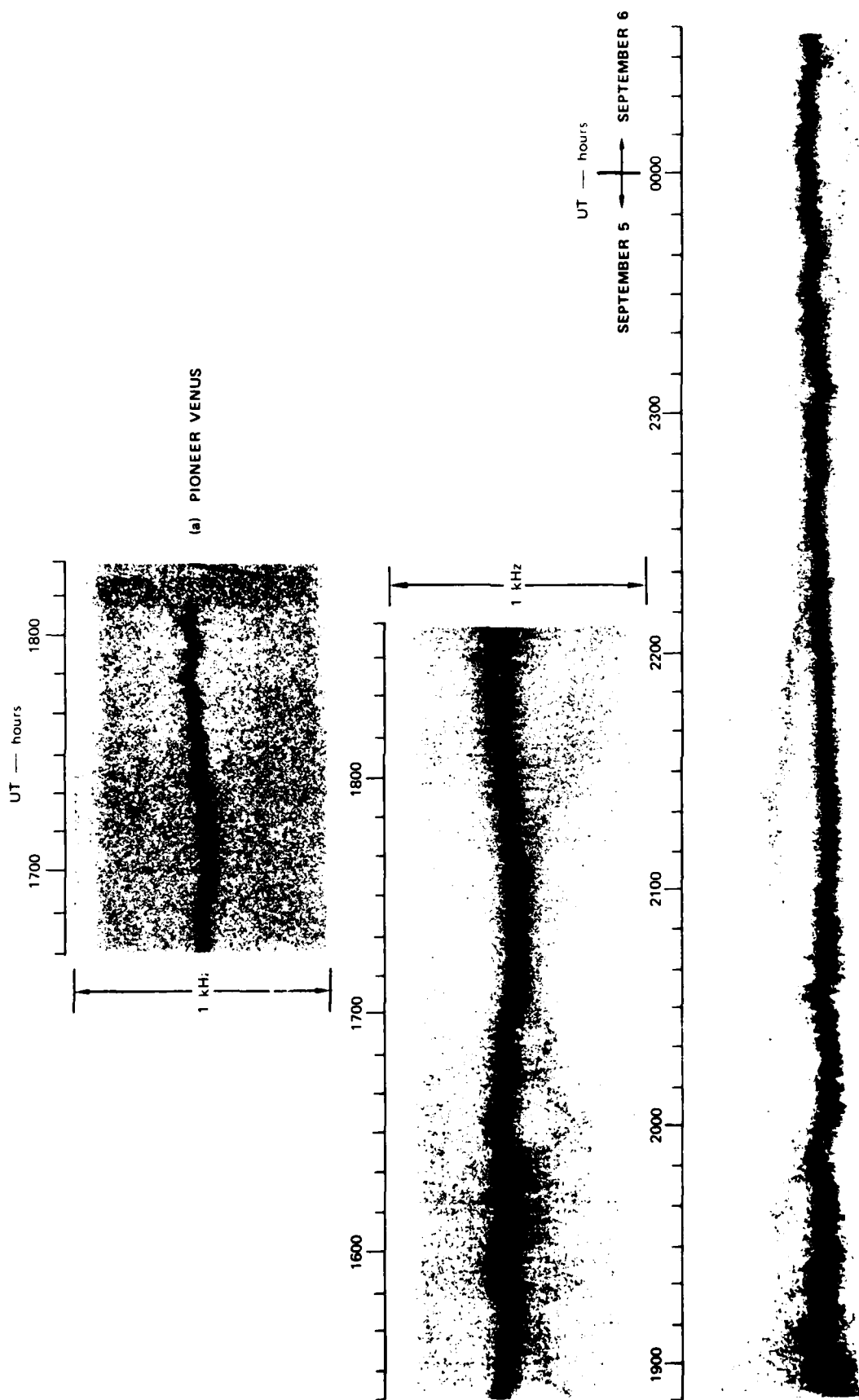


Figure 7

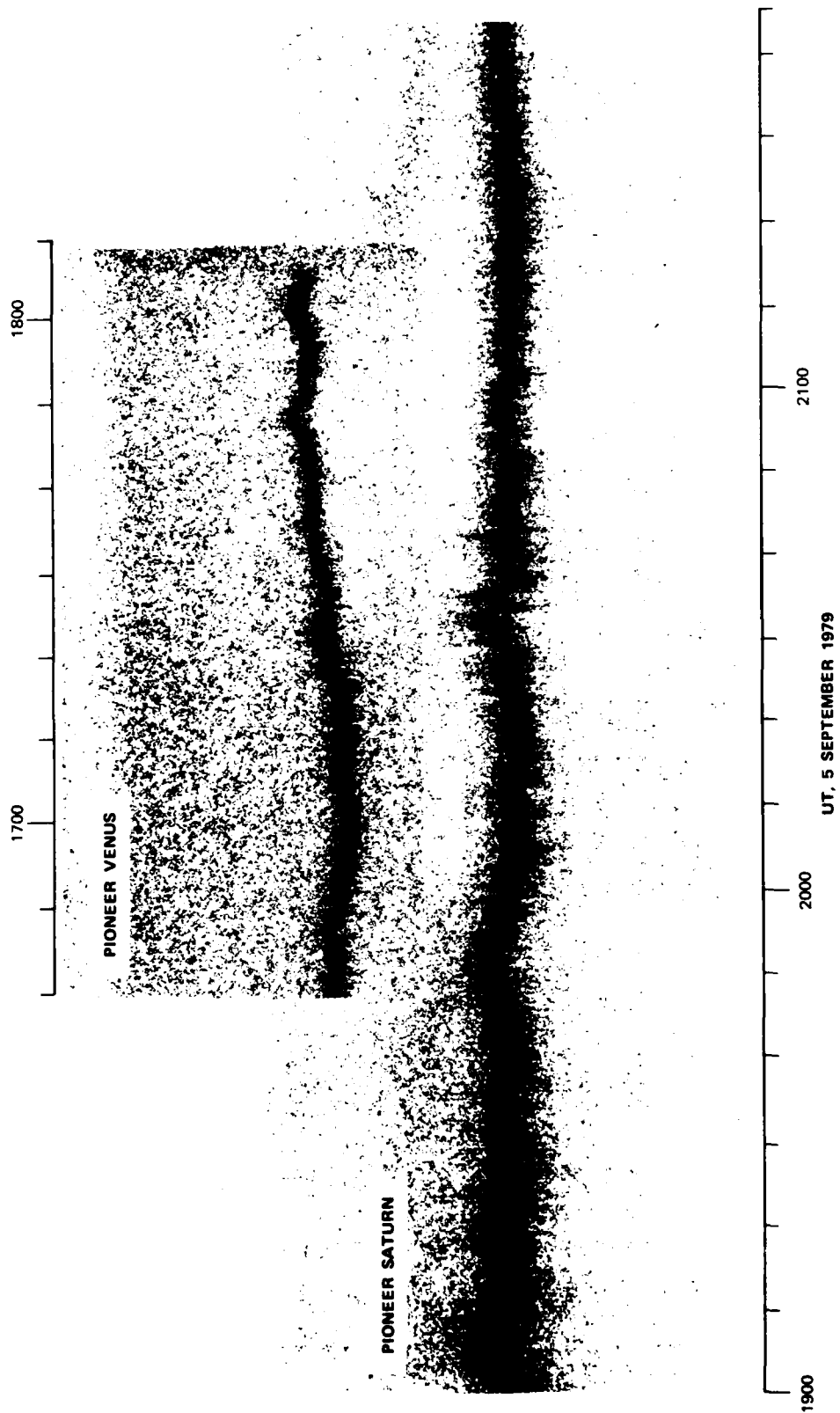


Figure 8

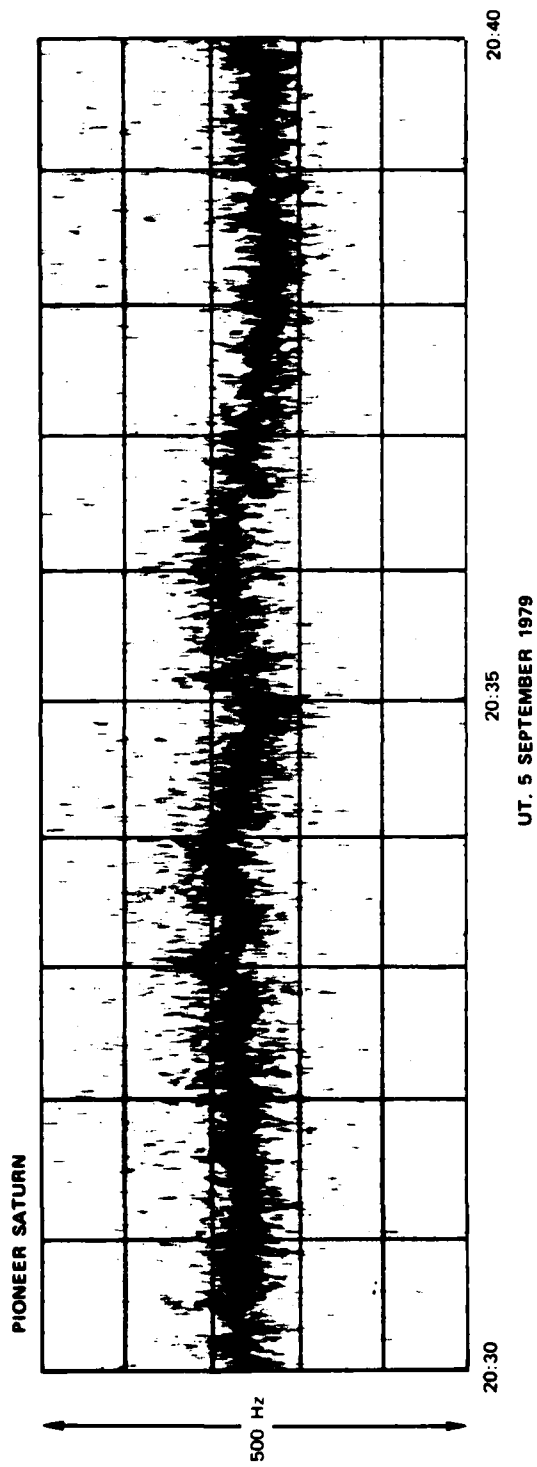


Figure 9

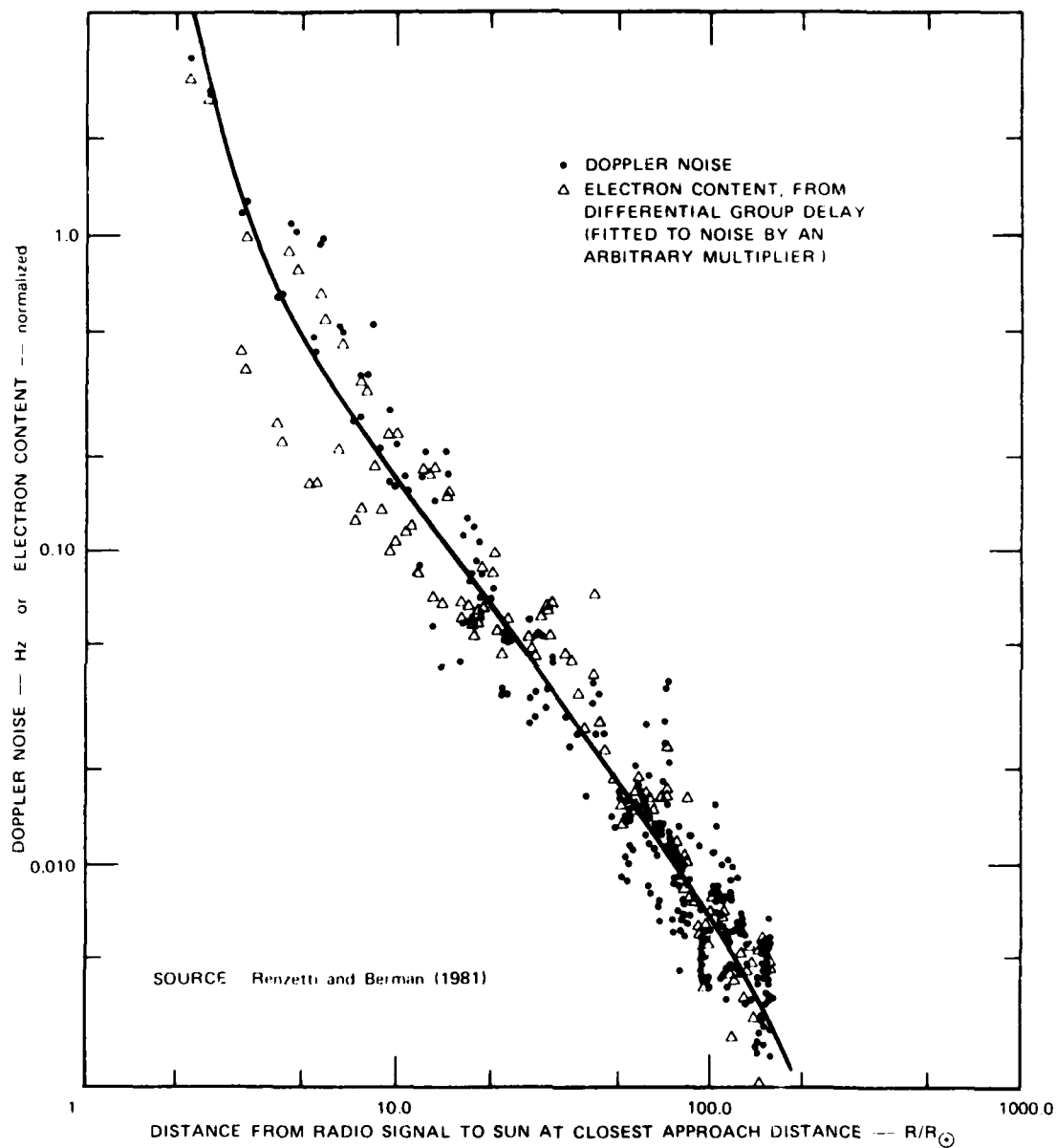


Figure 10

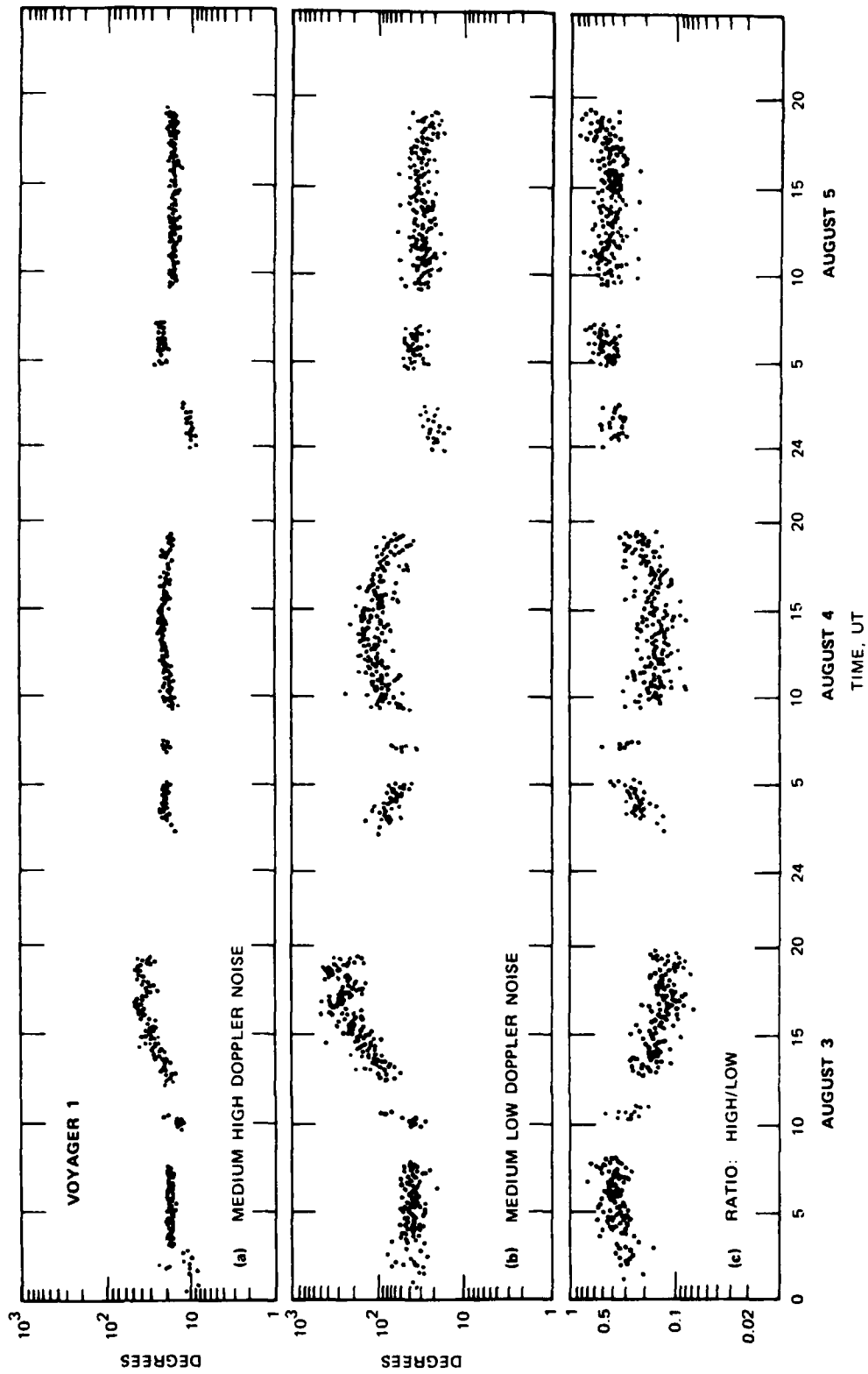


Figure 11

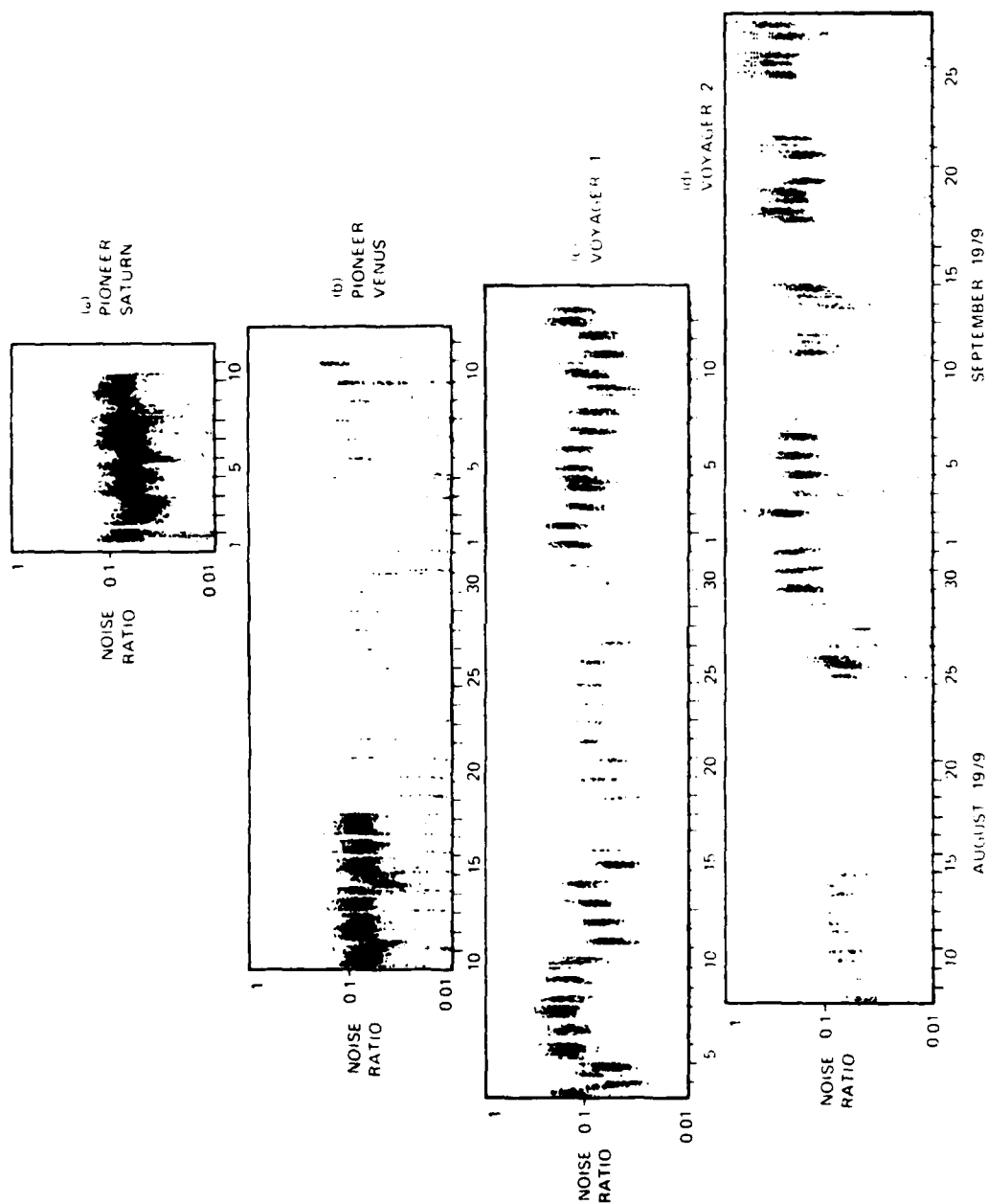


Figure 12

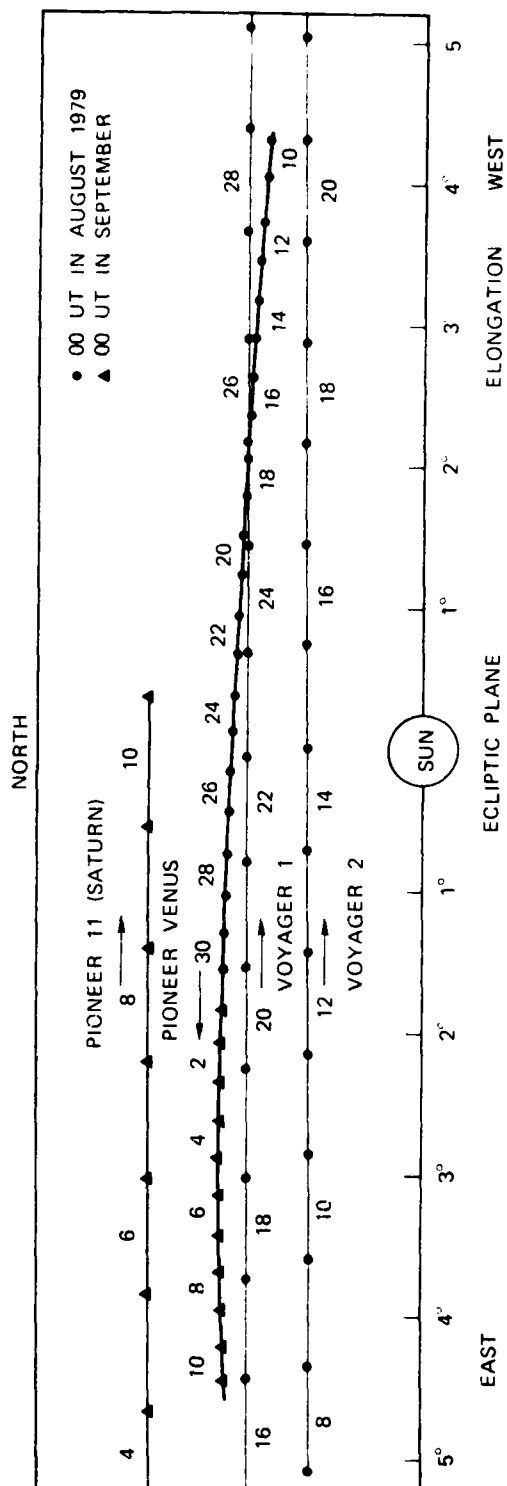
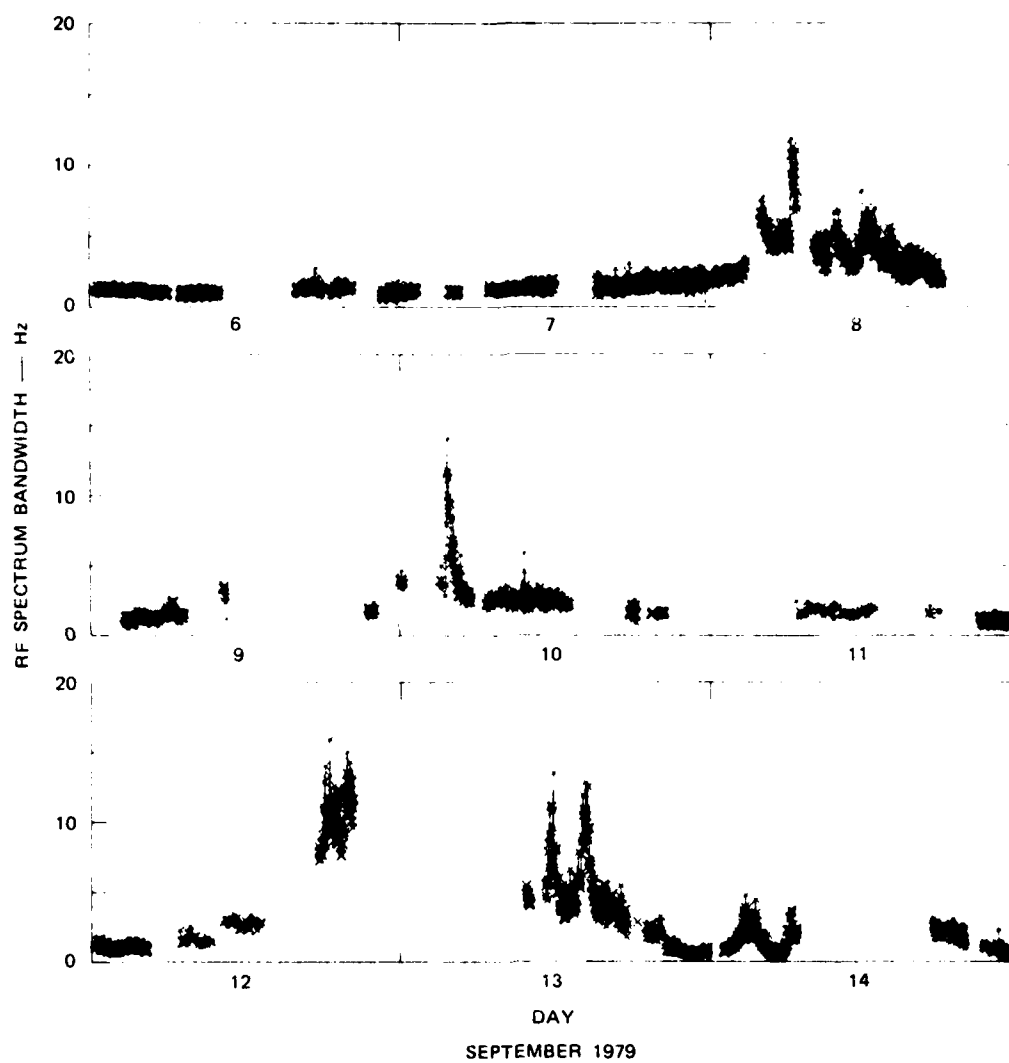


Figure 13



SOURCE: Woo and Armstrong, 1980

Figure 14

